THE BENTHIC ECOLOGY AND COMMUNITY STRUCTURE
IN LYTTELTON HARBOUR
CHRISTCHURCH NEW ZEALAND

A thesis presented for the degree
of Master of Science in Zoology
in the
University of Canterbury
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by

Grant Knight

1971

..."Well, the computer analysis didn't do any better than (or as well as) I could, but it wasn't a bad job and perhaps it gave me an odd idea here and there"...

Johnson (1968) pg 32 Proc. Linn. Soc. N.S.W. 93

LIST OF FIGURES

Addendum

Fig. 10: Graph illustrating Stokes' law, relating current velocity and sediment transport.

Erratum

Fig. 15.11: For *Sepiola* read *Sepioloidea*.

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SECTION 1

LYTTELTON HARBOUR; GENERAL DESCRIPTION AND SAMPLING METHODS

1.1 Introduction

Lyttelton Harbour, one of the many shallow, muddy bottomed inlets around the New Zealand coast, has a number of unusual features that affect the enclosed water. The harbour's location and the volcanic origin of Banks Peninsula affect the water temperatures, turbulence, turbidity, and the current directions and intensity, (Fig.1). These are detailed in the following chapters.

The volcanic material, along with the loess coating the hills around the harbour, has a controlling effect on the amount and type of sediment on the seafloor, The fauna living in and on the substrate must be considered in relation to the physical characteristics of the environment before any conclusions on the existence of possible communities may be formulated. The first section details the methods used in the analysis of these characteristics and the equipment used to sample the fauna.

1.2 Description of the Study Area:

Lyttelton Harbour is 13km long and covers an area of 44 square km. It lies in two adjoining basalt domes formed by the Lyttelton and Akaroa volcanos which were active in the Cretaceous. This was followed by a period of deposition of marine sandstones and greensands in the mid-Tertiary. Further eruptions in the Oligocene buried these. Subsequent sub-aerial erosion reduced the area to an erosion cauldera which was drowned, thus forming the present basin. (Brodie 1955)

1.2.1 Topography:

The floor of the harbour rises with an average gradiant of 1:100 (Map N.Z. 6321 Lyttelton Harbour). The deepest part is at Godley Head from where the depth decreases steadily to Governors Bay which is largely uncovered at low tide, (Fig 2). Over a large area surrounding Quail Island, Charteris Bay and Purau Bay the depth is constant at 3.5 - 5.5 metres. Only at two places are rocks exposed on the harbour floor. These are Parsons Rock, north of Ripapa Island, and Shag Reef, north-east of Quail Island, midway between Quail Island and the mooring basin.

Most of the harbour shore is fringed by cliffs that have been cut into the solidified lava. Alternating with this, and particularly around Quail Island, similar cliffs have been cut in the deep loess deposits.

The harbour is surrounded by hills, averaging about 400 metres in height, formed by the lip of the Lyttelton Harbour volcano crater. This topography tends to restrict the inflow of freshwater from the local catchment (Maps N.Z.M.S. 2 S 84/4 and S 84/5)

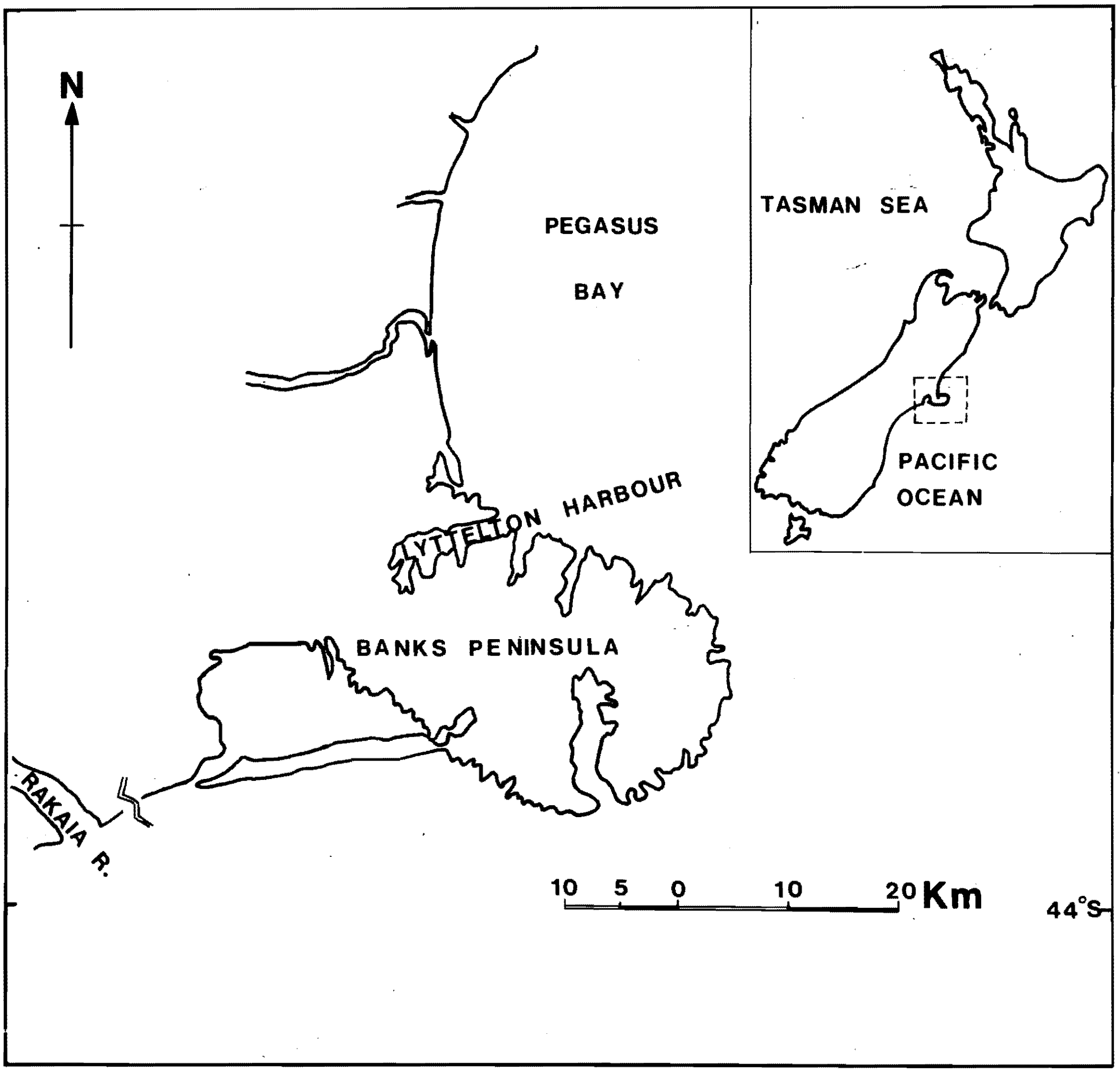
1.2.2 Hydrology:

Wave action is generally small. It usually is of low amplitude and long wavelength. Normally the swell is 100 metres long and 1 to 1.5 metres high. The wave base from this extends to about seven metres and disturbs a great deal of mud in the upper harbour.

While this type of swell generally results from oceanic disturbances, it may be accentuated by winds from the north-east and south-west. These are locally strong due to the funnelling effect of the surrounding hills.

FIGURE 1.

Lyttelton Harbour relative to the rest of New Zealand


N
PEGASUS
BAY
LYTTELTON HARBOUR
BANKS PENINSULA
RAKAIA R.
TASMAN SEA
PACIFIC
OCEAN
10 5 0 10 20 Km
44°S

The choppy seas produced by these two influences may be further increased where they are acting against the tidal flow. In this case, short seas of two metres may arise very rapidly.

There is a large annual variation in the sea water temperature in Lyttelton Harbour (Fig. 3). Within the harbour during the summer months surface temperatures are appreciably higher than those offshore. This is due to the harbour enclosing large areas of shallower water which are readily heated by solar radiation. Conversely, in winter, temperatures tend to be lower than in the open sea because of the combined effects of the inflow of cold fresh water, low air and ground temperatures, and general atmospheric cooling. (Skerman 1958).

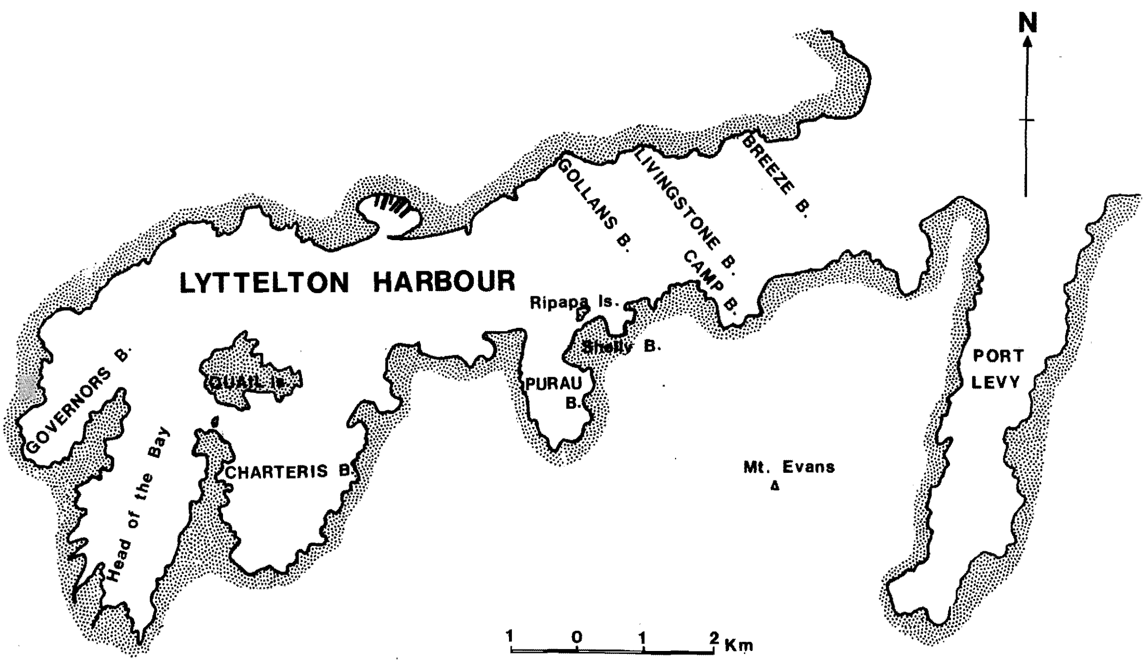
Currents, because of their direct relationship to sediment distribution, are dealt with in Section 2 (Sediments).

1.2.3 Dredging:

The harbour has been artificially deepened by dredging since 1877. The primary object of this is to maintain a channel 10.4 metres deep up the centre of the harbour as far as the wharves and the manoeuvring basin opposite the wharves area entrance. From 1877 to 1961 34 million tons of material was moved. In 1961 the Harbour Board took delivery of a new dredge, the "Peraki", and in the past nine years, an additional 36 million tons has been removed, a 1000 percent increase. This material is dumped within the harbour, either in Gollans Bay, Breeze Bay, Livingstone Bay, or Camp Bay according to the state of the tide at the time of dumping, (Captain Chrisp pers comm.). Dumping has reduced the depths of the above

FIGURE 2.

Details of the harbour and the adjacent bays.


N
LYTTELTON HARBOUR
GOLLANS B.
LIVINGSTONE B.
BREEZE B.
CAMP B.
Ripapa Is.
Shelly B.
PURAU B.
GOVERNORS B.
QUAIL Is.
Head of the Bay
CHARTERIS B.
Mt. Evans
PORT LEVY
1 0 1 2 Km

mentioned bays by about four metres. This material is unstable, continually slumping into the channel, and being moved up the harbour by tidal flows, (Harbour Board engineer, pers. comm.).

Consequently, much of the northern side and some of the southern side of the harbour is covered with a poorly sorted layer of dredged material (see Fig.8). This situation is, of course, not favourable for the establishment of the benthic animals. For this reason the study area was restricted to the upper undredged parts of the harbour.

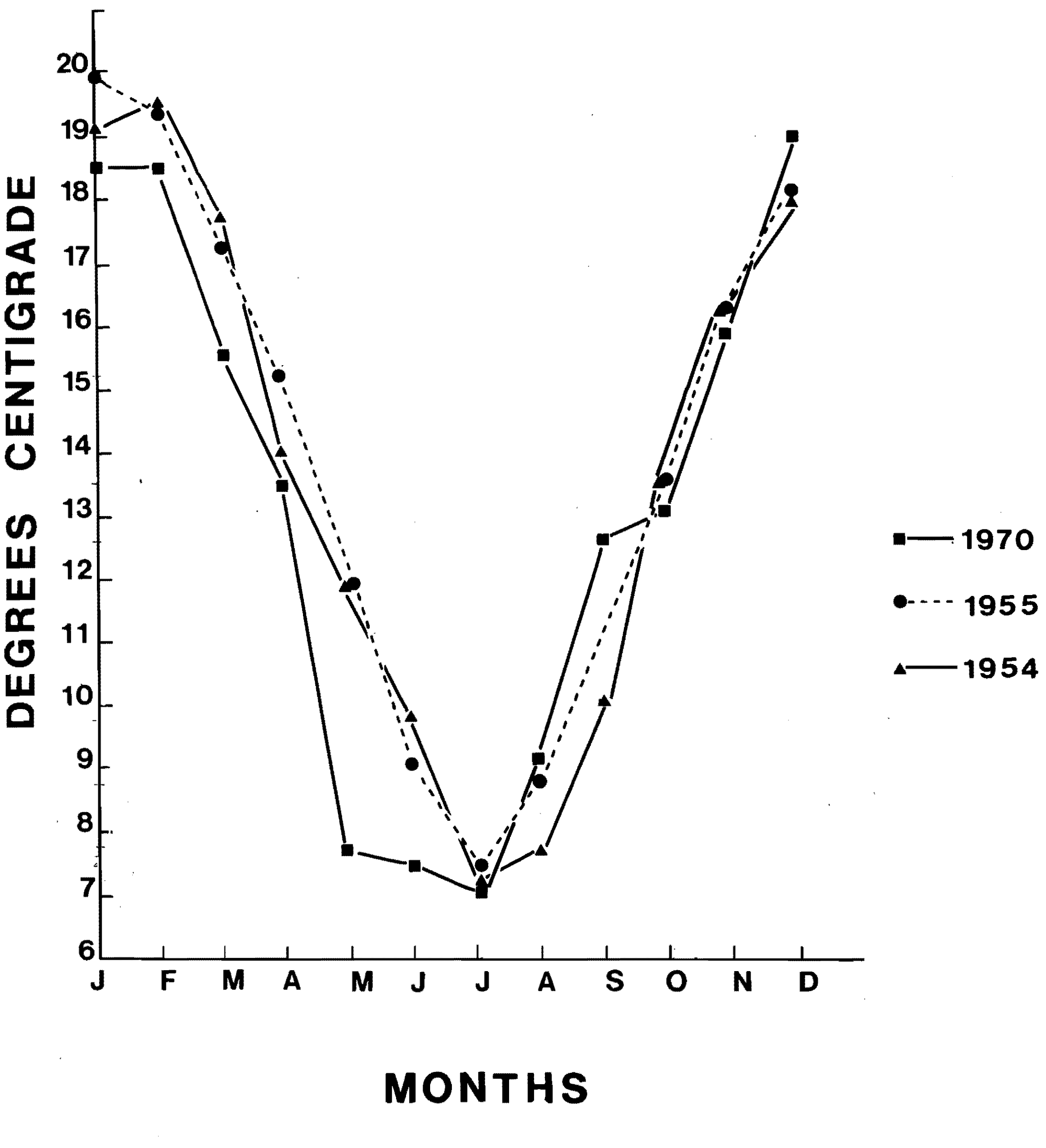
Figs 4. and 5. show four transects across the harbour comparing depths in 1849 before any dredging was undertaken (Brodie, 1955), from a survey made by the H.M.S. Acheron, and in 1951 when the last official survey was completed by Commander J.M. Sharpy-Schafer from the H.M.S. Lochlan.

Overall there appears to be a slight deepening, which is not surprising considering the amount of sediment that has been removed in dredging. The change is very small and it might be that the rate of erosion of the loess from the surrounding hills is increasing with intensive farming tending to remove the vegetation and expose the soft clays. It has been calculated by Brodie (1955) that the amount removed from the harbour for reclamation and deepening is equivalent to a decrease of two inches in the height of the local catchment. This is about the amount that Furkert (1947) considers represents the average rate of erosion in a similar area.

The net decrease in the sediment mass therefore may be rather small relative to the amount removed. The small rate of change over the last hundred years does strengthen the assumption that the region is stable.

FIGURE 3.

Annual ranges of temperature in Lyttelton Harbour for the years 1954, 1955, and 1970.


DEGREES CENTIGRADE
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
J
F
M
A
M
J
J
A
S
O
N
D
MONTHS
1970
1955
1954

This contrasts sharply with the opinion of several local residents of Lyttelton and Governors Bay, that the harbour has drastically shallowed, and that, in the early years of the century, large craft could be moored at the Governors Bay wharf at mid to low-tide, where, at the present time mud banks are high and dry.

1.3 Identification of Sampling Sites

A map of the harbour was covered by a 400 metre grid pattern and suitable numbers added for ease of location of particular sampling sites, (see Fig. 6). Four hundred metres was chosen as the smallest practical size, allowing for errors in navigation during fieldwork.

1.3.1 Review of sampling equipment

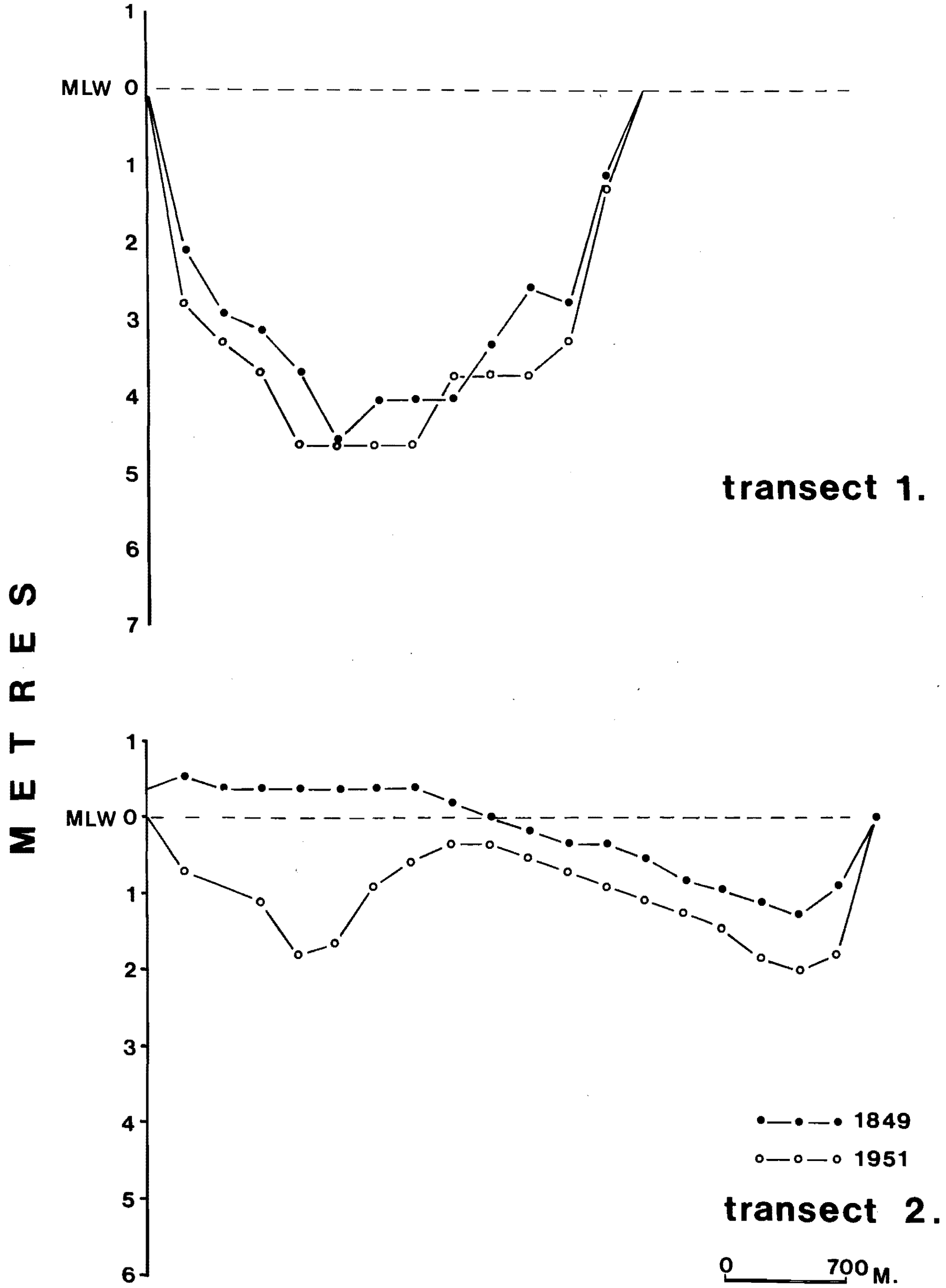
Petersen, the first worker to seriously undertake quantitative sampling, used a wide range of samplers based on a two jawed grab still known as the "Petersen Grab". This, despite its extreme simplicity, did a very good job on soft and muddy sediments but generally did not penetrate very well in sands, particularly coarse, well packed material.

Attempts were made to improve the leverage of the closing mechanism by adding long arms that acted in a scissor-like arrangement. This was known as the "Van Veen" grab and described by Thamdrup (1938). Smith and MacIntyre (1954) mounted a modified Petersen grab in a frame and added a pair of powerful helical springs that drove the jaws into the sediment once it had settled squarely on the bottom.

These modifications solved the problem of poor digging in hard sediments but did not overcome the basic

FIGURE 4.

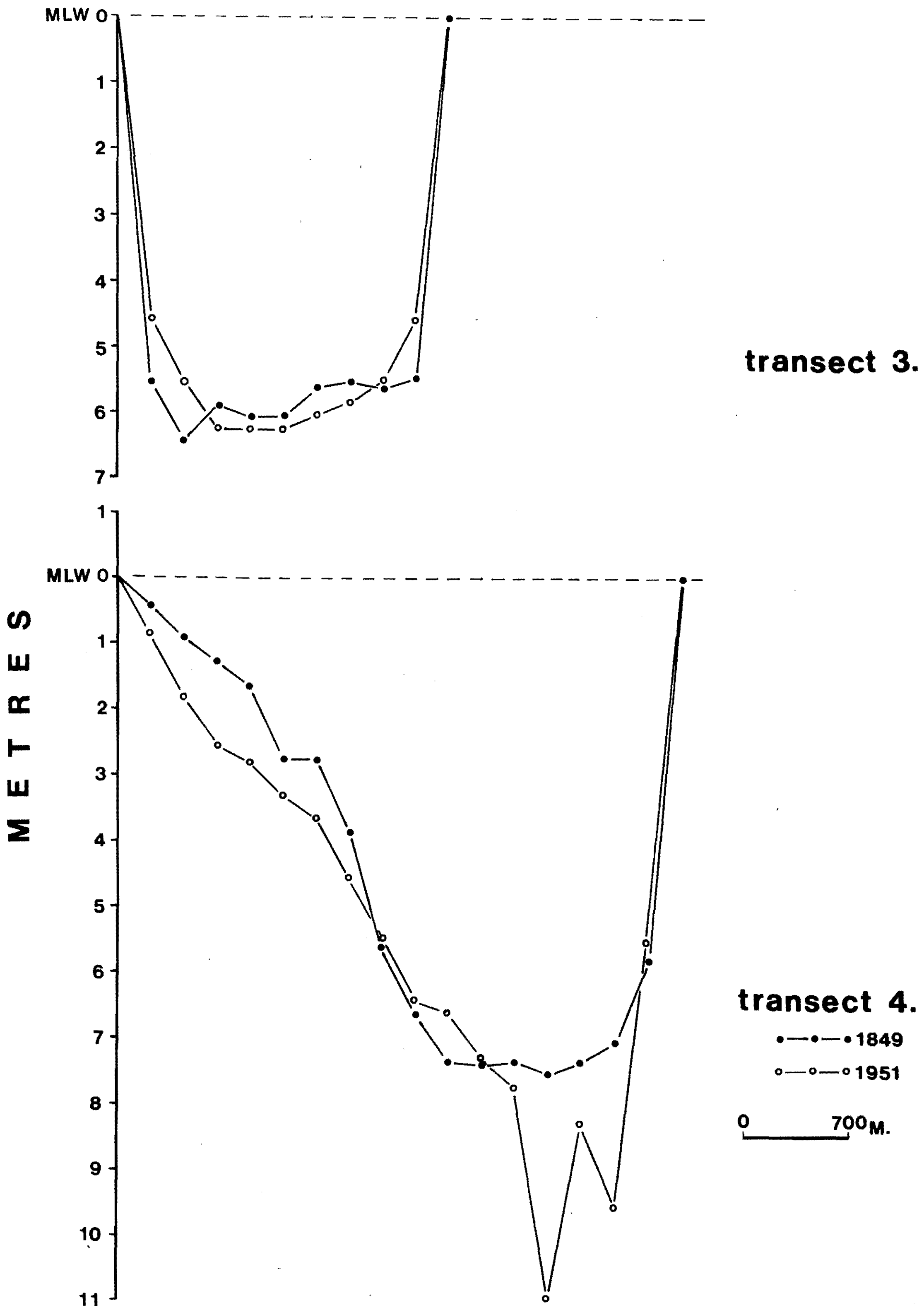
Transects across Lyttelton Harbour comparing depths in 1849 and 1951. Transect (1) runs from k16 to f12 and transect (2) from 015 to i4.



METRES
MLW 0
1
2
3
4
5
6
7
transect 1.
1849
1951
transect 2.
0
700 M.

FIGURE 5.

Transects across Lyttelton Harbour comparing depths in 1849 and 1951. Transect (3) runs from j17 to f14 and Transect (4) from i20 to f17.



MLW 0
1
2
3
4
5
6
7
transect 3.
1
MLW 0
1
2
3
4
5
6
7
8
9
10
11
METRES
transect 4.
1849
1951
0
700M.

fault of all of these types of grab. The sample that is taken has a depth differential with the depth of the sample increasing towards the point where the jaws meet. This may mean that the deeper burrowing animals are under-sampled. This is very difficult, and in many cases impossible, to correct for.

A similar criticism may be made of the "Orange Peel" grab described by Hartman (1955). Although this sampler usually penetrated well, the area covered by the jaws was impossible to calculate and the depth differential was even more pronounced.

These drawbacks were overcome to a great degree by the development of core samplers, Knudsen (1927), Holme (1949), where both the area covered and the depth penetrated may be very accurately known.

Both the grabs and the corers take a very small sample, usually about 0.1 or 0.2 square metres. Considering the normal density of benthic fauna this gives, statistically, a very poor sample and many consecutive grabs are required to properly describe the dispersion and density of the fauna.

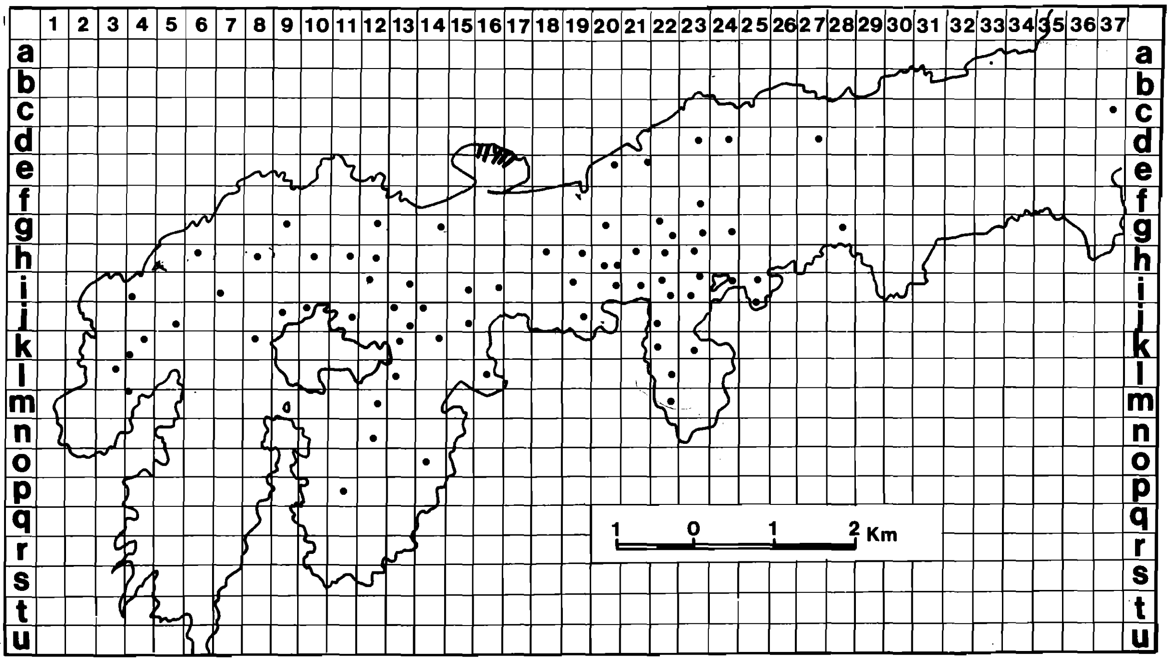
The solution to the problems of depth and small sample came with the development of various dredges. The anchor dredge (Forster, 1953) was found to be capable of digging to about ten centimetres even in hard packed sand. Sanders (1956) utilised the evenness of the digging by deriving quantitative data from collections.

Although criticism has been frequently made of the validity of the data from dredge samples, this can usually be refuted provided the digging characteristics are well known.

Samplers designed to take epifauna are a relatively new development and have not been widely used except for

FIGURE 6.

Map of Lyttelton Harbour showing the 400 metre grid used to identify sampling sites.


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
a b c d e f g h i j k l m n o p q r s t u
1 0 1 2 Km

very deep water studies where the scarcity of fauna makes it necessary to cover very large areas to capture a representative sample of the animals present. They have been found, though, to be of equal value in shallow water situations where they are far superior to dredges in the collection of fast moving species.

1.4 Methods of Sampling

The key to efficient sampling of a benthic habitat is a knowledge of the modes of life of the fauna. These are:

(a) buried in the substrate, possibly at considerable depth;

(b) attached to the surface, either directly or on a stalk; and

(c) free roaming and often capable of rapid movement.

In practice one grab or dredge is not capable of efficiently sampling all these organisms. Therefore, instead of using one sampler and attempting to apply corrections for likely escapement, it was decided to try four specialised pieces of equipment that would sample selectively, and then pool and compare results.

The devices used were:

1. The "orange peel" grab;

2. A box dredge; This sampler was built in the workshop of the Zoology Department of the University of Canterbury, having been modified from a design by P.J. MacIntyre (1964). MacIntyre's was considerably larger, weighing about one ton when fully loaded. The present version has a box of 34 cm by 9 cm and when full holds about two litres of sediment. The lighter weight means that it can be hauled to the surface by hand if necessary.

3. An epibenthic sledge. This sampler, as with the box dredge, is based on an already established design published by Hessler and Sanders (1967). Again it is smaller, being 30cm across the mouth and is fitted with a 1mm Terylene mesh bag. This device may also be used without the aid of a winch.

Because the "orange peel" grab was very heavy (54Kg.), it penetrated up to 30 cm into the sediment giving a deep sample. The box dredge, although digging only to a depth of 7.5cm., gave a much larger sample from each drag. Both of these samples were very slow in their action and the "orange peel" had the big disadvantage of producing a shock wave as it fell, dislodging any light object from the point of impact.

These two disadvantages were overcome by using the epibenthic sledge which could be towed at about three knots and still maintain an efficient water flow through the net. This sampler was excellent for catching such forms as mysids and swimming crabs that were not found in the dredge hauls. The sledge also collected any epiphytic organisms and sampled the top half centimetre of sediment.

4. It was also desirable to investigate the plankton in the water immediately above the substrate. This was sampled with a sledge that did not accept any sediment, but sampled the bottom twenty centimetres of water.

1.5 Efficiency of the Samplers

As a check on the relative catches of the first three samplers, they were all used over the same area and the resultant catches compared. The results of this are shown in Fig. 7. The numbers of the dominant animals vary widely with the type of gear used, and it is clear that any one sample could have implied a false assemblage of animals.

Detailed consideration of Fig. 7 showed clearly that the epibenthic sledge was far superior in catching the faster moving and more agile animals. This showed in the catches of the shrimp Pontophilis australis, the squid Sepioloidea pacifica, and the crab Halicarcinus whitei. It also had a slight advantage in the collection of epiphytics and those animals living close to the surface. These included the pycnogonid Achelia variabilis and the gasteropod Zegelerus tenuis.

The box dredge and the orange peel grab showed a distinct advantage in the collection of infauna. This was evident in the numbers of Myadora striata a small infaunal lamellibranch, and Hemiplax hirtipes, a burrowing crab. It seemed likely that Hemiplax descended into a burrow at the approach of the sampler and only those who could not get to shelter were taken by the epibenthic sledge.

In most cases there was not a great difference between the performances of the box dredge and the orange peel grab. The exception was in the collection of the oyster Ostrea heffordi, and Spisula aequilateralis a small bivalve, where the box dredge showed an advantage. Possibly this is because both of these animals showed a patchy distribution and it was more likely that the box dredge be dragged across an area where they occurred than for the orange peel grab to fall directly upon that spot.

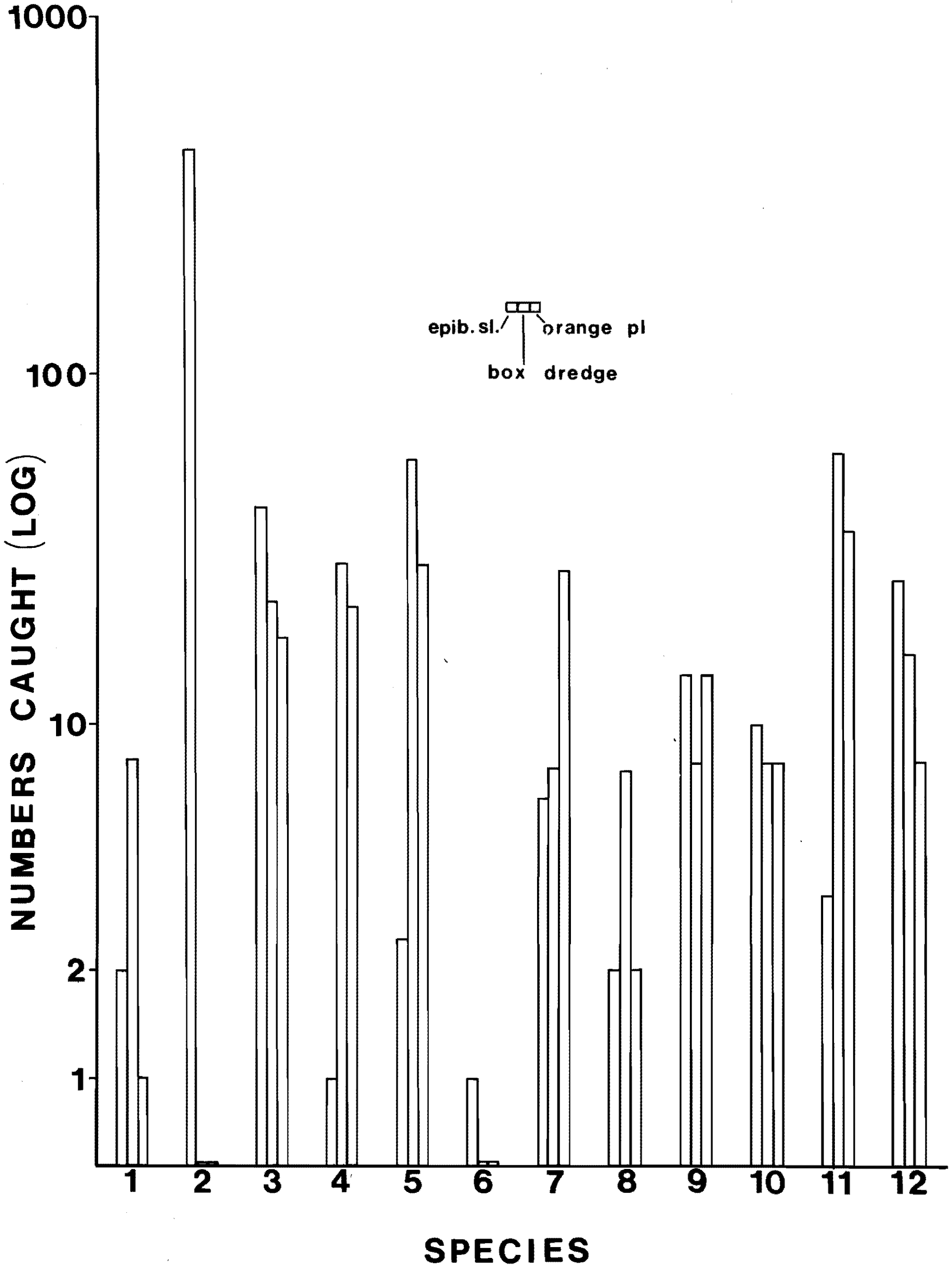
On the basis of the results it was decided to concentrate on using the box dredge and the epibenthic

FIGURE 7

The relative catches of the three types of sampler used in the study.

Species list

1. *Ostrea heffordi*
2. *Pontophilus australis*
3. *Achelia variabilis*
4. *Pectinaria antipoda*
5. *Myadora striata*
6. *Sepioloidea pacifica*
7. *Virgularia gracillima*
8. *Spisula aequilateralis*
9. *Xymene plebejus*
10. *Zegelerus tenuis*
11. *Hemiplax hirtipes*
12. *Halicarcinus whitei*


epib. sl.
orange pl
box dredge
1000
100
10
2
1
NUMBERS CAUGHT (LOG)
1
2
3
4
5
6
7
8
9
10
11
12
SPECIES

sledge for future sampling with the occasional use of the plankton sampler. The reasons for discontinuing the use of the orange peel grab were;

1. it was too heavy, and overtaxed the winch gear on the boat;
2. the area sampled by the jaws was difficult to calculate;
3. the depth of penetration varied greatly with the type of substrate;
4. the jaws were often jammed open by gravel and shells and
5. the sample was washed on the way up even though a canvas cover had been placed over the jaws.

Quantitative sampling does not allow any of the above errors. The box dredge had a known capacity of 0.03 cubic metres and dug to known depth so the area and volume sample could be reliably calculated.

1.6 Sampling techniques

Sampling was carried out over transects covering areas of interest, generally crossing regions of variable substrate. The boats, initially the "Trade Wind" owned by Mr E. Johnstone and later the "Pup" skippered by D.J. Partington, were allowed to drift with the wind and swell using the dredge. Experiments by MacIntyre (1964) showed that the dredge dug on the downstroke of the swell and was stationary on the upstroke. This reduced the bouncing that was apparent when it was being continually pulled. Five minutes was enough to fill the dredge box on any surface; usually less time was sufficient.

When the epibenthic sledge was being used the boat was stopped and the sledge lowered. It then went slowly ahead and the rope, normally twice the depth being worked, was paid out. After the towing period the boat was stopped and then put astern while the rope was pulled in. This simplified calculations of the distance covered since the sledge did not move between the end of the drag and the lifting off the bottom.

Observations by divers of the operations of an epibenthic sledge showed that it moved forward smoothly when towed at slow speeds sinking, at the most, only two centimetres into a soft mud substratum (Sanders and Hessler 1967).

1.7 Treatment of Samples

When dealing with large muddy samples, such as the box dredge load, it was not sensible to hand sort, although this probably caused less damage to the collected animals than other methods. Four stacked sieves of 8mm, 2.5mm, 1.5mm, and 0.4mm were used in this study. The sediment was flushed away using a deck hose and the fauna thus was sorted into four size classes. Animals then were hand picked off the sieves and transferred to a weak formalin solution.

Prior to the sieving a 200ml sample was taken for analysis of grain structure and organic carbon content. This was stored in natural seawater to avoid inaccuracies caused by the addition of preservatives (Morgans 1956).

1.8 Treatment of sediment samples

The sediments may be classified into sand, sandy mud, or muddy according to the relative amounts of the various grain sizes. For the analysis two methods were used, sieving and pipetting. The first of these, sieving, separated the coarser fraction into seven grades after thirty minutes agitation on a "Rotap" shaking machine. The material that passed through the finest sieve was suspended in a solution of sodium hexa-meta-phosphate in distilled water. This acted as an anti-flocculant. Using the principle that the settling velocity of particles is proportional to their diameter the suspension was placed in a one litre cylinder and pipette samples extracted from a constant depth after pre-determined times. (For details see appendix 1.)

Details of the results of the sediment analyses are tabulated in appendix 3. For computer analysis only one subsieve grade was used. This combination gave eight divisions that covered most of the sand to mud criteria. These data were later used in a multivariate computer program.

The other parameter estimated was the amount of organic carbon in the sediments. This was measured using a modified "Walkley and Black" wet combustion method using hot chromic acid and titrating with ferrous sulphate. Diphenylamine was used as an indicator. This method estimated the percentage of "available carbon" ignoring the carbon in empty shells and particles of calcium carbonate. It is however affected by salt in the sediment and this is corrected for by subtracting one twelfth of the percentage of salt in the sediment from the calculated carbon content. Since carbon is only one of several major atoms making up organic molecules the calculated value may be multiplied by 2.4 to estimate the percentage of organic matter in the sample (see appendix 2 for full details).

1.9 Analysis of the data

One of the most satisfactory ways of analysing data to define communities is by multivariate analysis. A discriminate analysis computer program was selected from the I.B.M. scientific subroutines package and used in the University of Canterbury's I.B.M. 360/44 computer.

Preliminary examination of the data resulted in the selection of 24 of the most widespread animals as indicator species and in the selection of 40 of the 70 stations for incorporation in the analysis program. These stations had well sorted sediments that could be readily placed into one of the three categories - sand, sandy mud, or mud - and had also been analysed for organic content. The data were then punched onto computer cards so that each station was examined for the presence or absence of indicator species. Sediment data were added before the deck was processed.

SECTION 2

SEDIMENTS

2.1 Introduction

Benthic animals living in and on bottom sediments are vitally effected by changes in the type of sediment. This is particularly true of animals which use the sediment as a food source, and to a lesser degree of those where it is necessary for anchorage and protection. In addition to mineral particles, or clay, sediments usually contain a small proportion of organic detritus. This material is defined by Darnell (1967) as all types of biogenic material in various stages of microbial decomposition which represent potential energy sources for consumer species. It includes all dead organisms as well as secretions, regurgitations, excretions and egestions of living organisms together with all the subsequent products of decomposition which still represent potential sources of energy. This portion of the sediment has been analysed for al all sites sampled.

Most of the mineral fraction is of a size larger than colloidial. The organic detritus includes colloidal, miscelles, as well as chemically reduced organic molecules, which often remain in suspension almost indefinately. It also contains molecular aggretates or large molecules such as proteins, carbohydrates, and lipids. There is also a certain unavailable portion, the lignins. These are very resistant organic complexes formed by living plants. Their decomposition is extremely slow (Waksman and Tenney 1926). In aerobic soils they are decomposed in traces or not at all (Waksman and Stevens 1929, 1929a).

2.2 Sediment sources

Three major rivers discharge along the east coast of the South Island; the Waimakariri, Rakaia, and the Rangitata. These have contributed the bulk of the Canterbury plains and most of the shallow water sediments but it is doubtful if much of this has penetrated to the upper reaches of Lyttelton Harbour.

The main source of the harbour sediment is the loess that coats the hills surrounding Lyttelton to a depth of about seven metres. This is fine, wind-blown clay that is easily transported by water and readily forms a dense suspension. There are very few permanent streams flowing into the harbour but these rise rapidly with heavy rainfall and a very large amount of material can be moved onto the mud flats in a very short time. This material is well sorted and contributes to the lack of variety of texture in the upper harbour sediments. Most of the hill country is intensively grazed with only pockets of scrub remaining in the gulleys. During the summer the porous top soil dries, loosens and rapidly erodes.

The coarser grades are mainly derived from andesites and trachytes, the volcanic rocks that are exposed along most of the shoreline. Circumstantial evidence for this comes from the fact that olivine crystals are found in most sediment samples examined microscopically. These crystals are formed within the solidified lava.

2.3 Coastal Drift

Analysis of sediment samples from off the Avon-Heathcote estuary and the Waimakariri mouth by Reed

(1951) showed almost identical characteristics. They were mineral assemblages of quartz, feldspar, biotite, horneblende, augite, sphene and zircon derived principally from the feldspathic sandstones and siltstones that compose most of the Waimakariri catchment.

Sharpy-Schafer (1950) discussing the probable mode of transport of the material stated that under normal conditions the rate of longshore drift was less than 0.25 knots, except where stronger drift occurred during wave breaking and the consequent conversion of energy. However, much stronger drift takes place when northerly gales, to which this coast is particularly exposed, are blowing. Under these conditions large waves drive sediment against the northern side of Banks Peninsula where it accumulates, being sheltered from southerly wave action which has a similar effect on the southern facing bays. Sediments from the Waimakariri catchment are present at the heads but do not appear to travel in on the flood tide current, since none of the harbour sediments has the structure found by Sharpy-Schafer.

2.4 Sediment Depths

Only at two places on the harbour bed are rocks exposed. These are to the north of Ripapa Island and in square h13. Elsewhere the coverage is continuous with depths up to sixty metres measured by sinking piles to the "basement rock" for wharf construction (Captain Holden pers. comm.). No other detailed records of sediment depths are available at the present time.

2.5 Distribution of Sediment in the Harbour.

The greater part of the harbour is muddy. This is particularly apparent around Governors Bay, Head of the Bay, and Charteris Bay where large mud flats are exposed at low tide (Fig.8).

In the middle harbour, extending from Ripapa Island to the tip of Quail Island, there is a region of coarse sand which appears to be maintained by current action since this lies in the path of incoming tidal currents. This is fringed on the western side by an area of sandy mud which slowly grades into the pure muddy areas.

The sandy regions also contain a large proportion of crushed shell which adds to their coarse character. This is particularly true of the region opposite Purau Bay.

Reference was made in Section 2.2 to sediment derived from loess and alluvial action. These sediments, which are initially deposited unsorted are subjected to current action and are gradually sorted and redeposited.

Mention was made in Section 1.2.3 of dredging. This has disturbed the natural sedimentation, raised the bed of several eastern Bays, and there is also a constant drift back up the harbour of the dumped material.

2.6 Hydrodynamic Processes

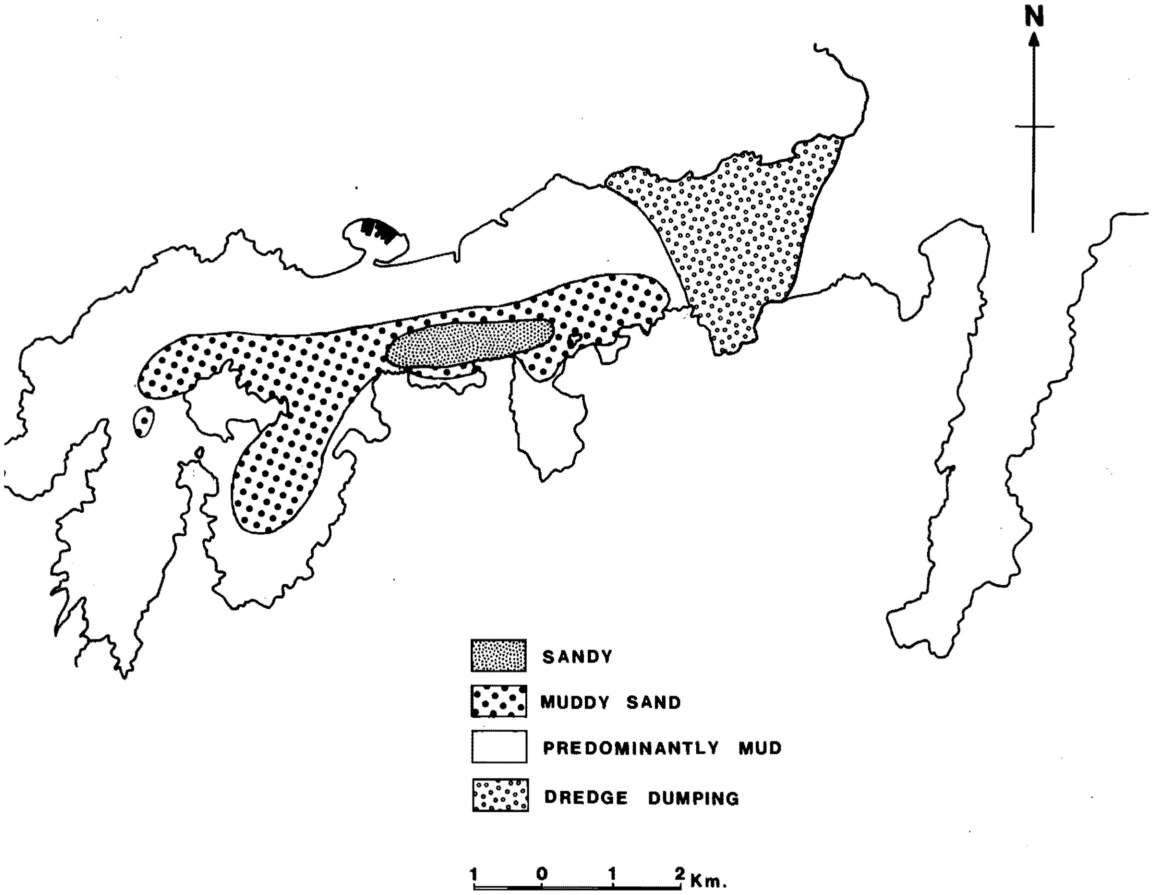
The distribution and character of sediments is controlled by three factors. These are:

1. The supply of raw materials:
2. Turbulence through wave action;
3. Current sorting.

The factor that is of greatest importance in the case of Lyttelton Harbour is current action.

FIGURE 8

Distribution of sediment types in Lyttelton Harbour.


N
SANDY
MUDDY SAND
PREDOMINANTLY MUD
DREDGE DUMPING
1 0 1 2 Km.

The currents follow the path shown in Fig.9, and they correspond fairly well to the map of sediment distribution in the Harbour (fig.8). At a current velocity, which can be determined from Fig.10, a lamina flow along the substrate surface will turn into turbulent flow capable of transporting material. This value is dependent on the velocity and the size of the particles projecting into the flow.

Wave action, although possibly not as important as current action in the deeper parts of the harbour, certainly has a considerable effect in the shallower upper harbour. Just above the mud surface there is a layer of mobile ooze, personally observed in Governors Bay. The water here is often very turbid. This may be apparent when sometimes the whole of the upper harbour is very discoloured when there is heavy wave action.

2.7 Action of Stokes' Law on sediment distribution.

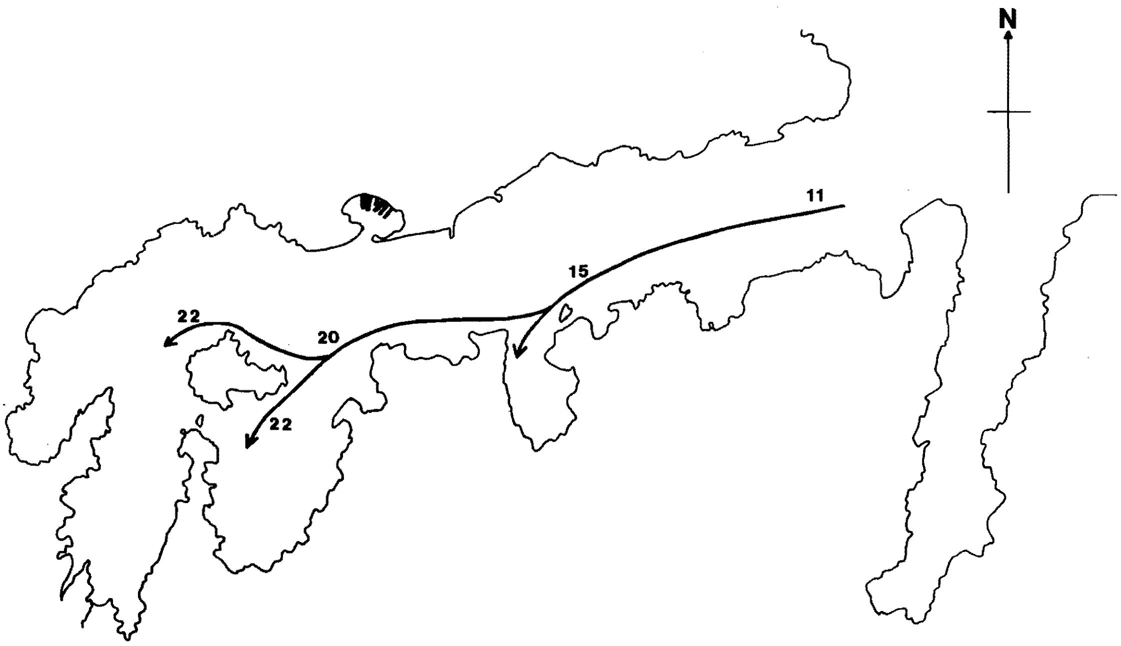
Stokes' Law predicts the settling velocity of particles up to 0.18 mm diameter. Below 0.18mm the relationship between size and velocity is linear, but above this figure turbulence created by the moving particles slows the settling below the particular values.

The threshold velocity at which the particle first begins to move, is at a minimum for 0.18mm diameter particles. Smaller particles produce a hydrodynamically smooth bottom and the drag does not effect individual particles to any extent. Fig. 10 relates current velocity and particle diameter depicting:

1. the velocity where laminar flow changes to turbulent flow;
2. the current velocity necessary to move the

FIGURE 9.

Directions and speeds in centimetres per second of incoming tidal currents in Lyttelton Harbour.


N
11
15
22
20
22

various sizes of grain;

3. the velocity that will allow settling of the particles.

It follows that in areas of maximum current, the sediment will consist of coarse grades and the mean size will become smaller as the current diffuses and slows.

2.8 Tidal Flow Patterns in Lyttelton Harbour

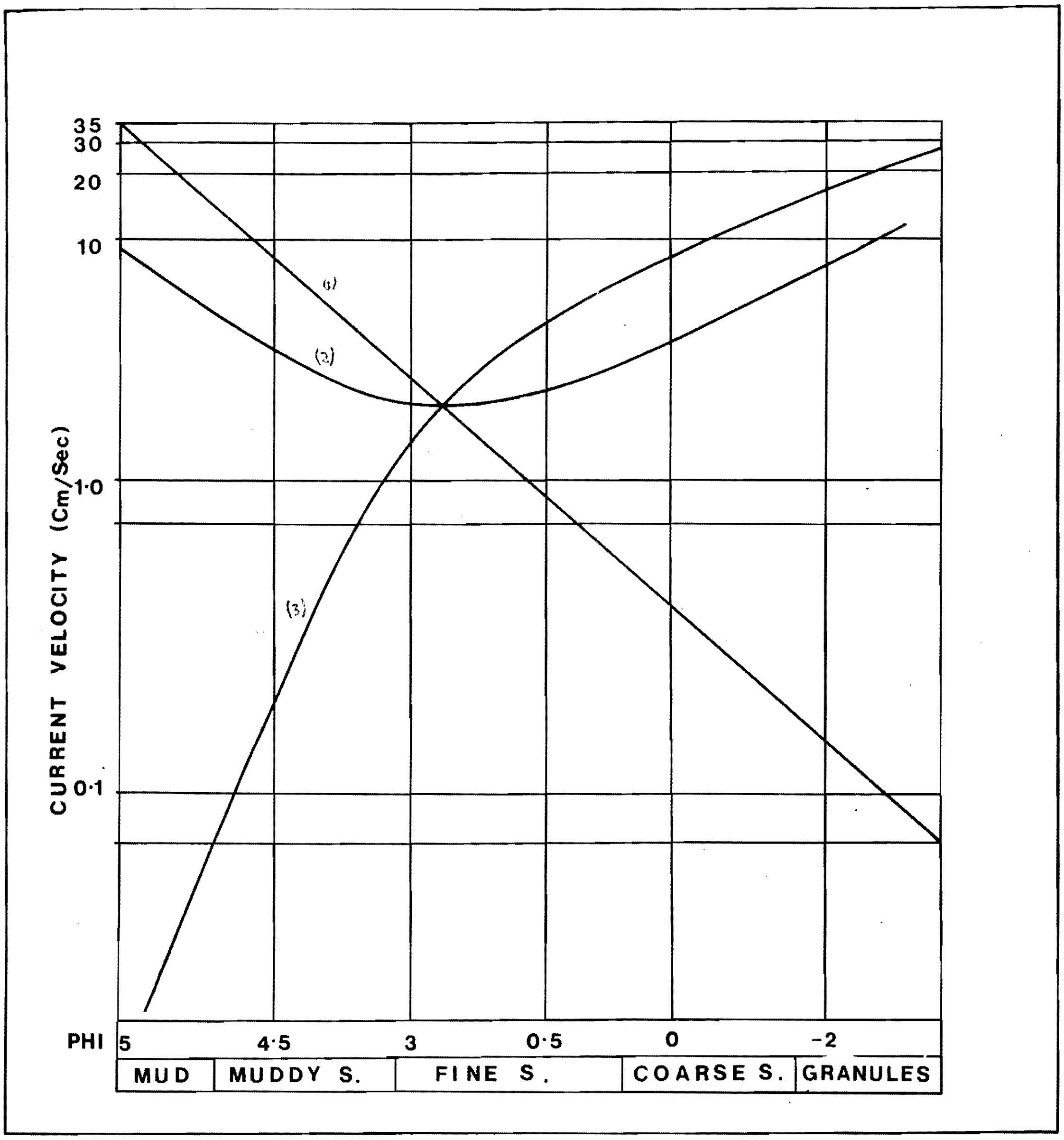
Garner and Ridgeway (1955) described the movement of fluorescent dye trails laid across the harbour and of biplane drag floats suspended at different depths. These showed that the most active kind of currents were along the south side of the harbour with velocities on the flood side of 0.4 knots or approximately 21 cms/sec in the area between Purau mouth and Quail Island, see Fig.9. This region is also shallow enough to be affected by the wave base when a strong swell is running. Thus there is ample scope for sediment sorting and redistribution. This general pattern has been confirmed by personal observations from a drifting boat. In addition it was observed that there were disturbances around the mouth of Purau Bay and the tip of Quail Island, where divergences were found. This resulted in a strong current down either side of Quail Island with a tendency for it to be stronger on the southern side.

Reference to the map of sediment types (Fig.8) shows that the areas of coarse materials are opposite Purau and Diamond Harbour extending up to, and alongside, Quail Island.

Evidence suggests therefore that these are maintained and sorted by the flood and ebb tide currents, which here reach a velocity of 22 cm/sec. Further

FIGURE 10.

Graphical representation of Stokes' Law relating current velocity and sediment transport modified from Inman (1949).



CURRENT VELOCITY (Cm/Sec)
35
30
20
10
1·0
0·1
(1)
(2)
(3)
PHI
5
4·5
3
0·5
0
-2
MUD
MUDDY S.
FINE S.
COARSE S.
GRANULES

reference to Fig.10 shows that a current of 20 cms/sec is capable of moving coarse sand quite easily.

2.8.1 Analysis of the Grain Size

After sieving and pipette analysis, (see appendix 2.) the resultant eight grades may be graphed either as a histogram or as a cumulative frequency curve. In depicting grain sizes the phi system has been adopted. Where the size of a particle in phi units is the negative log to the base 2 of the diameter in millimetres (see Fig. 11) this allows the curve of the distribution of particles to approach normality when there is not a great bias towards either end of the scale. This system has the advantage that it permits the use of well established statistical procedures. The four parameters of Central tendency, dispersion, graphic skewness, and graphic kurtosis can give a full description of sediment quality without reference to a curve relating the amount of each grade but are often used in conjunction with a curve, either relative amounts of each size class or cumulative frequency.

2.9 Descriptions of the use of the parameters, their limits and errors.

Mean and median may diverge and often one is more significant than the other. Both are easily derived from the cumulative frequency curve. The median is less affected by extremely skewed distributions and is closer to the mode. This measure is then more useful in predicting the most frequently occurring size. The mean, though, is more easily manipulated, the means of several sets of data, when averaged, giving a group mean.

FIGURE 11

Conversion chart for *phi* and diameters in millimetres.

$\phi = -\log_2$ diameter in mm

Phi (ϕ)	mm	ϕ	mm	ϕ	mm
-5	32	0.5	0.71	5	0.033
-4	16.00	1	0.50	5.5	0.022
-3	8.00	1.5	0.35	6	0.016
-2.5	5.65	2	0.25	6.5	0.011
-2	4.00	2.5	0.176	7	0.008
-1.5	2.83	3	0.125	7.5	0.0055
-1	2.00	3.5	0.088	8	0.004
-0.5	1.42	4	0.063	9	0.002
0	1.00	4.5	0.044	10	0.001

2.9.1 Measuring sorting or dispersion

This may be estimated from the phi deviation of the cumulative frequency curve. A vertical curve, indicating perfect sorting has a phi deviation of 0. The body of the curve between one standard deviation either side of the mean is normally used for this phase of the analysis. This measure may be affected by skewed curves.

2.9.2 Measures of skewness

In a normal, symmetrical distribution, the mean and median coincide. The extent of the departure may be used as a measure of skewness. This is expressed by the formula.

$$0 = \frac{0.5\ (\phi 16 + \phi 84)\ - Md\phi}{0} = \frac{M\phi\ -\ Md\phi}{0}$$

a secondary skewness measure may also be used. This takes into account the 5th - 95th percentiles and is sensitive to skewness in the tails of the graph whereas the primary skewness is concerned with the body of the curve. In the percent study only primary skewness is used.

2.9.3 Graphic kurtosis

This is a measure of peakedness and relies on the fact that according to the formula below, a normal curve registers 6.5. If the distribution has long tails, that is it is more evenly spread over the range, the value 0 is greater than 6.5.

$$0 = 0.5\ \frac{(\phi 16\ -\ \phi 5)}{0} + 0.5\ \frac{(\phi 95\ -\ \phi 84)}{0} = \frac{\frac{1}{2}(\phi 95\ -\ \phi 5)}{0} - 0$$

Where the range is small with an abrupt peak O is less than 6.5.

For each sampled site the distribution of sediment sizes was graphed and the above measurements made. These are detailed in Appendix 3. On the basis of these results areas were defined as sand, sandy mud or mud and used as the basis of community definition.

For the purposes of this study the sediments were divided up in the following manner; those falling between phi - 1.8 and +0.3 were termed coarse sands, those between 0.3 and 3 fine sands, muddy sand included material ranging from phi 3 to phi 4.7 and mud greater than phi 4.7. These classes are shown at the base of the Stokes' Law graph (Fig. 10).

2.10 Relationship between the organic carbon content of the sediments and grain size.

It has long been realised that the organic material within sediments forms an important source of food for benthic animals (Jensen 1915; Bond 1933; MacGintie 1932 and 1935; Darnell 1967) and that the quantity and quality varies with the type of sediment and proximity to river mouths and estuaries. It has been suggested by Fox, Isaacs, and Corcoran (1952), that many marine organisms are capable of absorbing suspended and dissolved organic matter and it has been suggested that the oceans may be regarded as a huge metabolizing cell (Fox, 1955), with the waters containing organic material representing the "sap".

Apart from the material in the water column, the organic detritus in the sediments is a heterogeneous system of particulate substances ranging in size from visible particles to colloidal micelles that are usually associated with the finest sediment, the clays. The quantities of organic matter absorbed onto solid surfaces as pelogloea may exceed the amounts suspended in the water by 10 times in coarser beach sand where there is commonly up to one percent organic matter. But adsorbed quantities may exceed suspended organic matter by 100,000 times in fine silt and bottom muds such as those in Lyttelton Harbour where the organic matter reaches 10 percent (Fig.12).

The amount capable of being adsorbed is a function of the grain size, the surface area of which increases rapidly as the diameter decreases. Fig.12 shows the change in the percentage of organic material as determined by the Walkley and Black wet combustion method, (see appendix 2). This is graphically related to the modal grain size. The sediments for this analysis were selected for their good sorting to minimize disturbance from the variation in grain sizes. A regression line was calculated using a computer program. This had the equation:

$$Y = -1.42 + 1.29 x$$

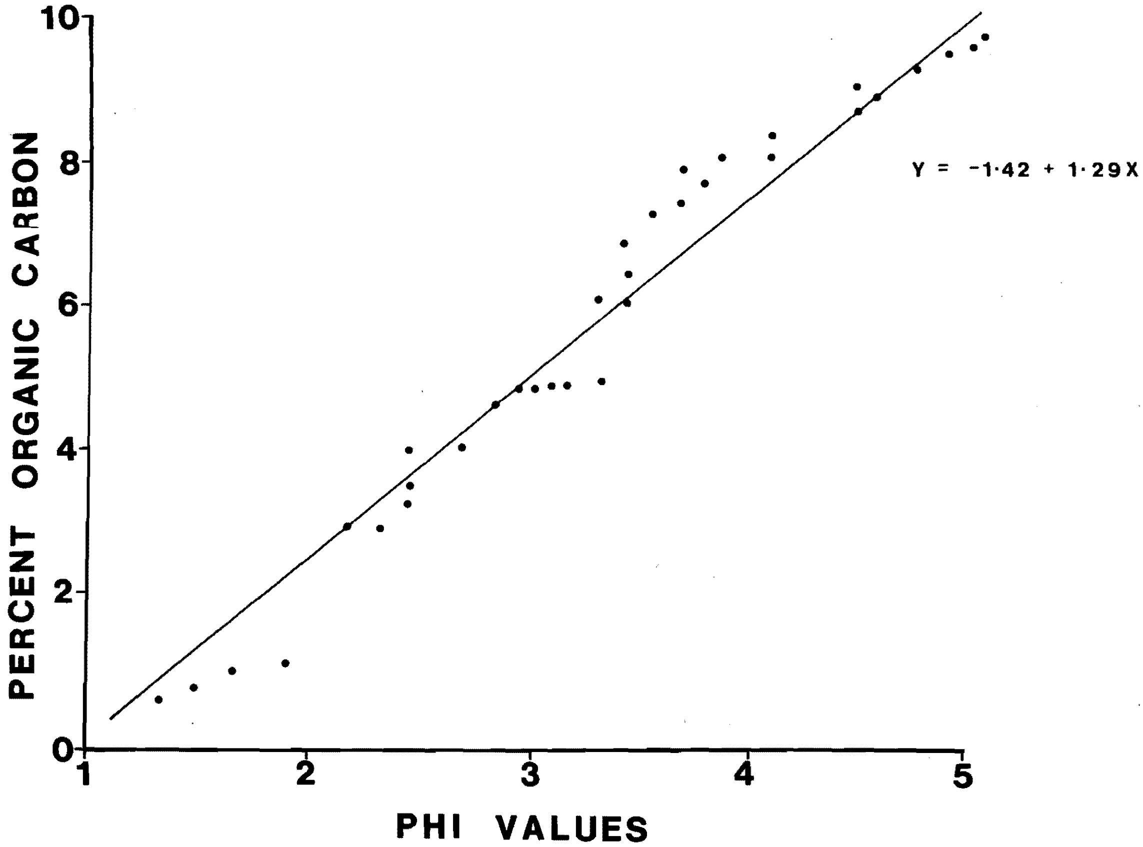
and a correlation coefficient of 0.92 showing fairly low scatter. Grain sizes larger than phi 1 had extremely small amounts of organic material but this rose in a linear fashion to reach about ten percent at phi 5.

2.11 Sediment types at selected sites

Forty sites among the 74 sampled over the investigation period were selected as being representative of all of the areas under investigation. The results

FIGURE 12.

Regression relating mean grain size and its organic carbon content.



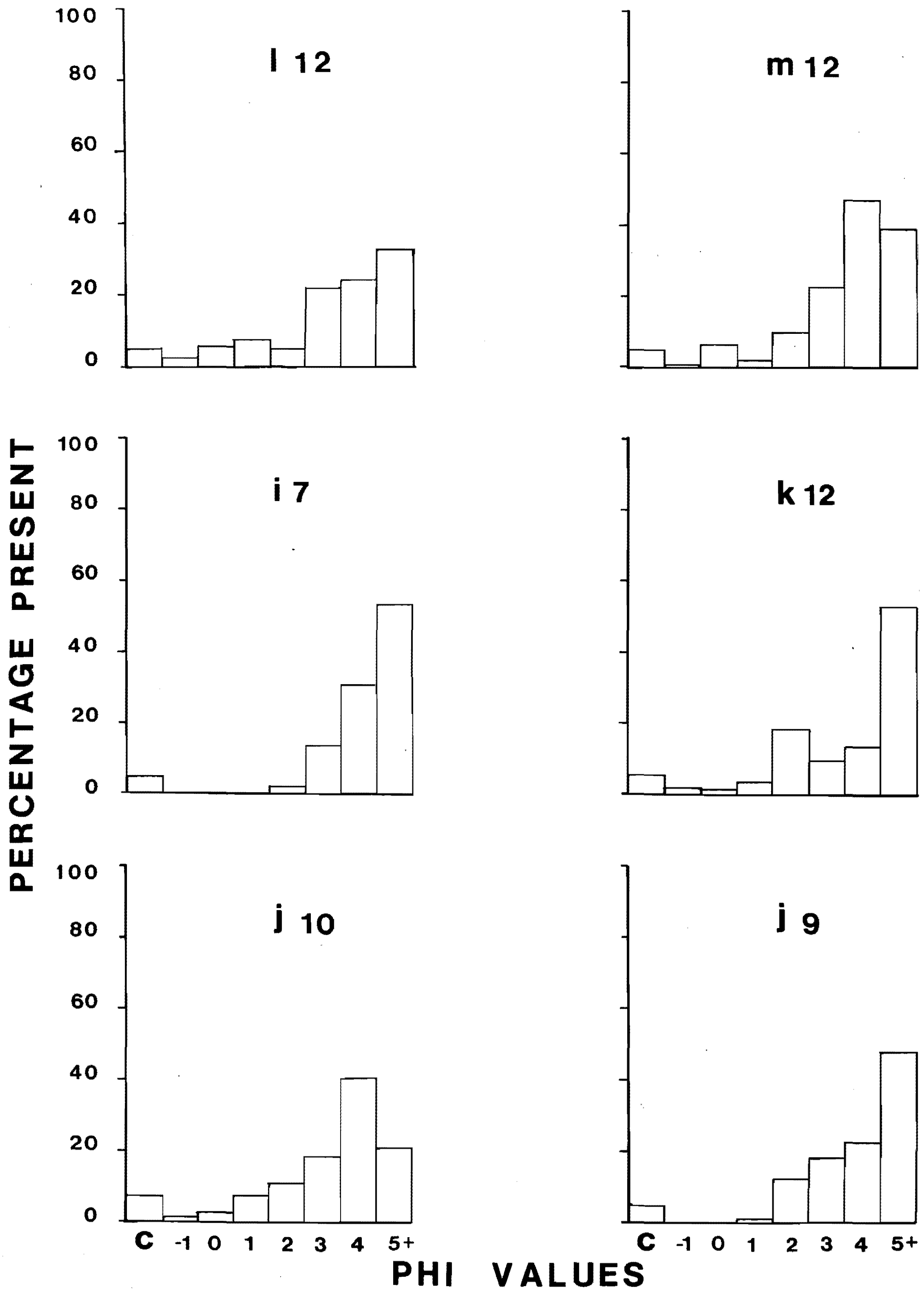
PERCENT ORGANIC CARBON
10
8
6
4
2
0
1
2
3
4
5
PHI VALUES
Y = -1·42 + 1·29X

of the sediment and organic carbon analyses were displayed as histograms (Fig. 13, 1 - 7). The first column on the left hand side marked C. is the organic carbon content of the mud measured by the Walkley and Black technique. The other seven columns represent the percentages of each grade of material measured in phi units.

The degree of sorting may be estimated by examining the columns and relating the percentage of the tallest to the average of the rest. This may be illustrated by consulting the histogram for site i22, (Fig 13.6), where the sediment is almost all about phi 4. Directly below this is the histogram for site i19, about 900 metres away where there is a wide range of grades making it very difficult to classify.

FIGURE 13.1

Size class distributions at sites 112, m12, i7, k12, j10, and j9.



l 12
m 12
i 7
k 12
j 10
j 9
100
80
60
40
20
0
PERCENTAGE PRESENT
C -1 0 1 2 3 4 5+
PHI VALUES

FIGURE 13.2

Size class distributions at sites k14, k8, m15, g14, i13, and h8.

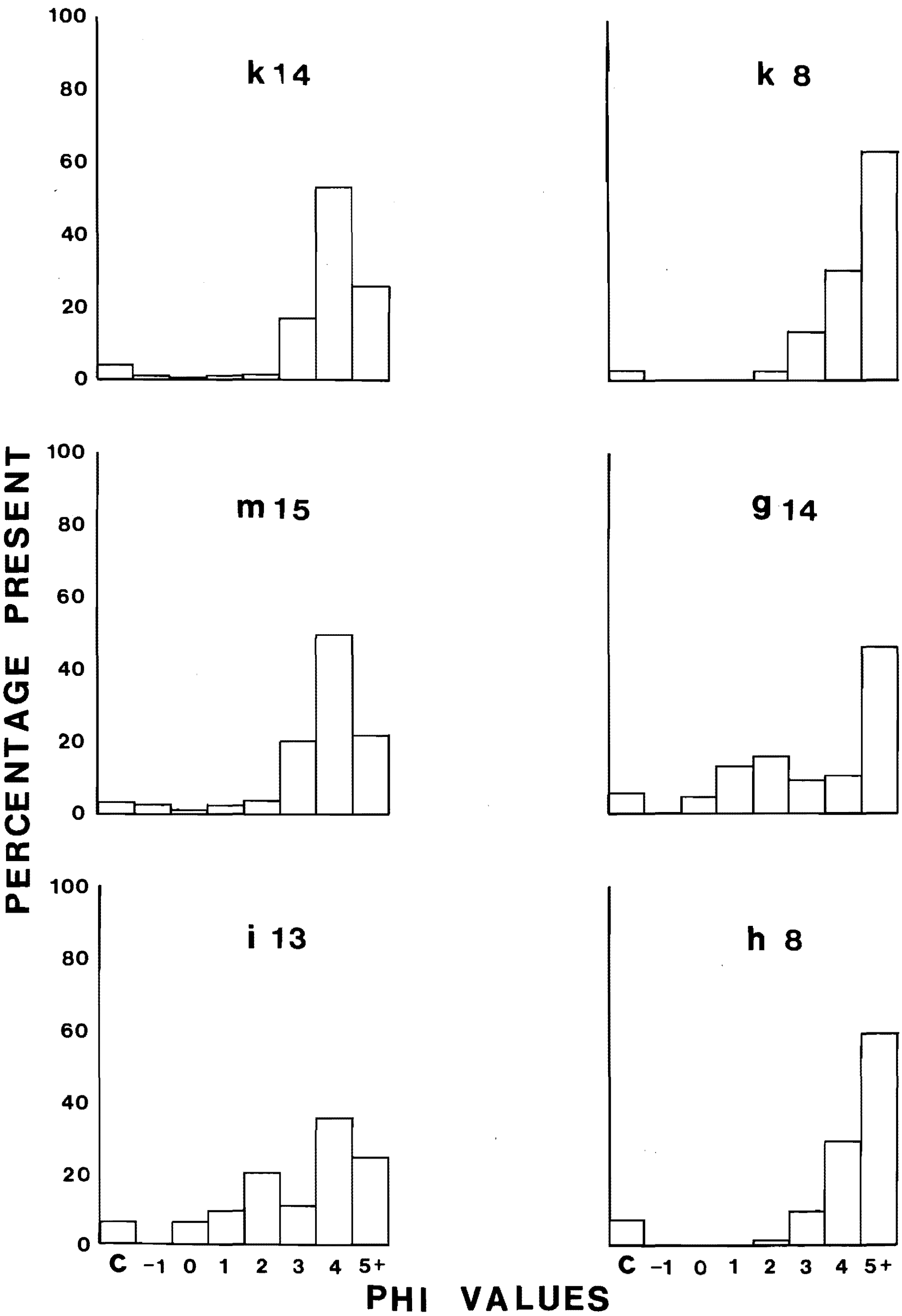
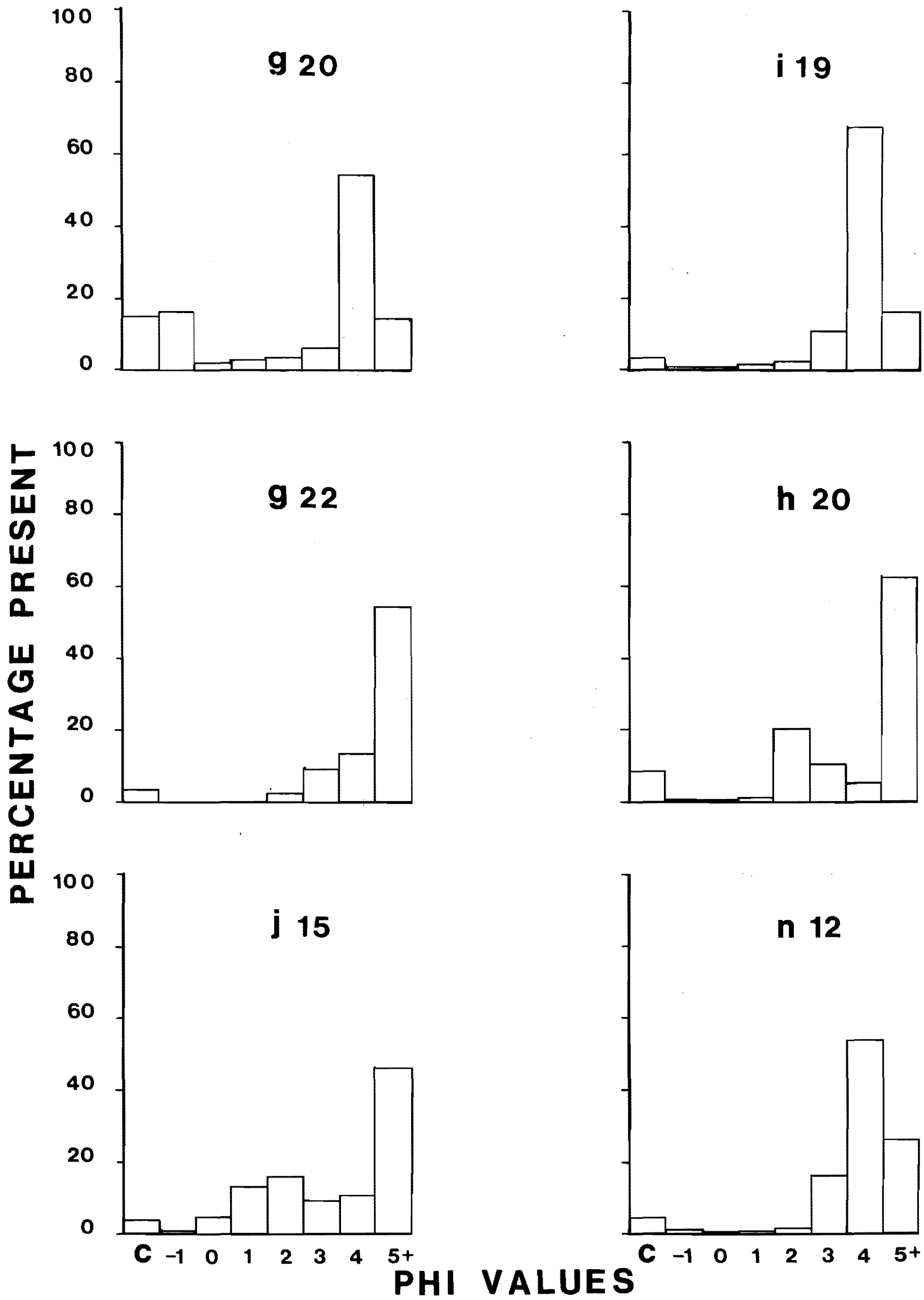

PERCENTAGE PRESENT
100
80
60
40
20
0
k 14
k 8
m 15
g 14
i 13
h 8
C
-1
0
1
2
3
4
5+
PHI VALUES

FIGURE 13.3

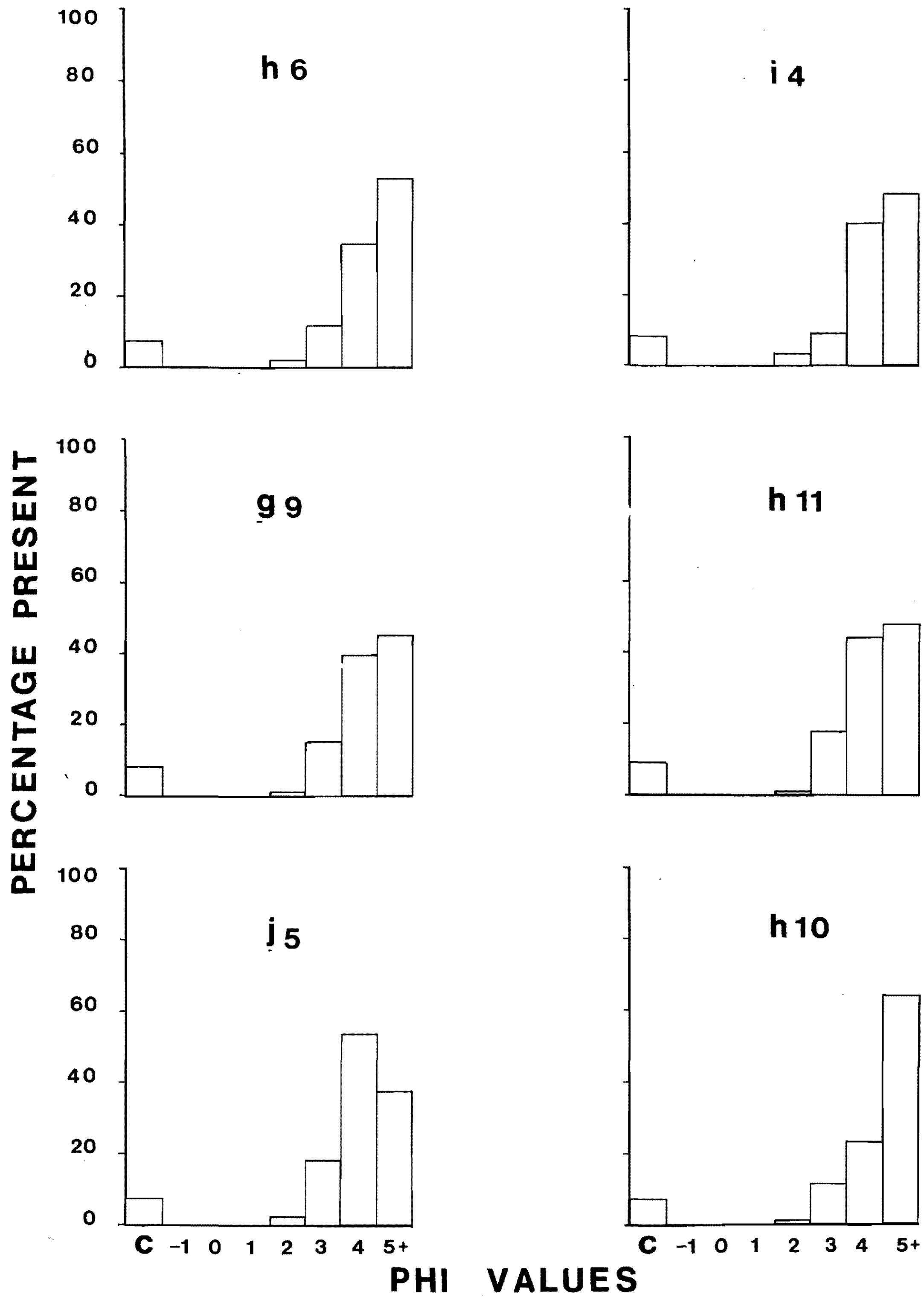
Size class distributions at sites g20, g22, h20, j15, and n12.



PERCENTAGE PRESENT
100
80
60
40
20
0
g 20
i 19
g 22
h 20
j 15
n 12
C -1 0 1 2 3 4 5+
C -1 0 1 2 3 4 5+
PHI VALUES

FIGURE 13.4

Size class distributions at sites h6, i4, g9, h11, j5, and h10.



h 6
i 4
g 9
h 11
j 5
h 10
100
80
60
40
20
0
PERCENTAGE PRESENT
C -1 0 1 2 3 4 5+
PHI VALUES

FIGURE 13.5

Size class distributions at sites g28, j24, i24, i23, i25, and j21.

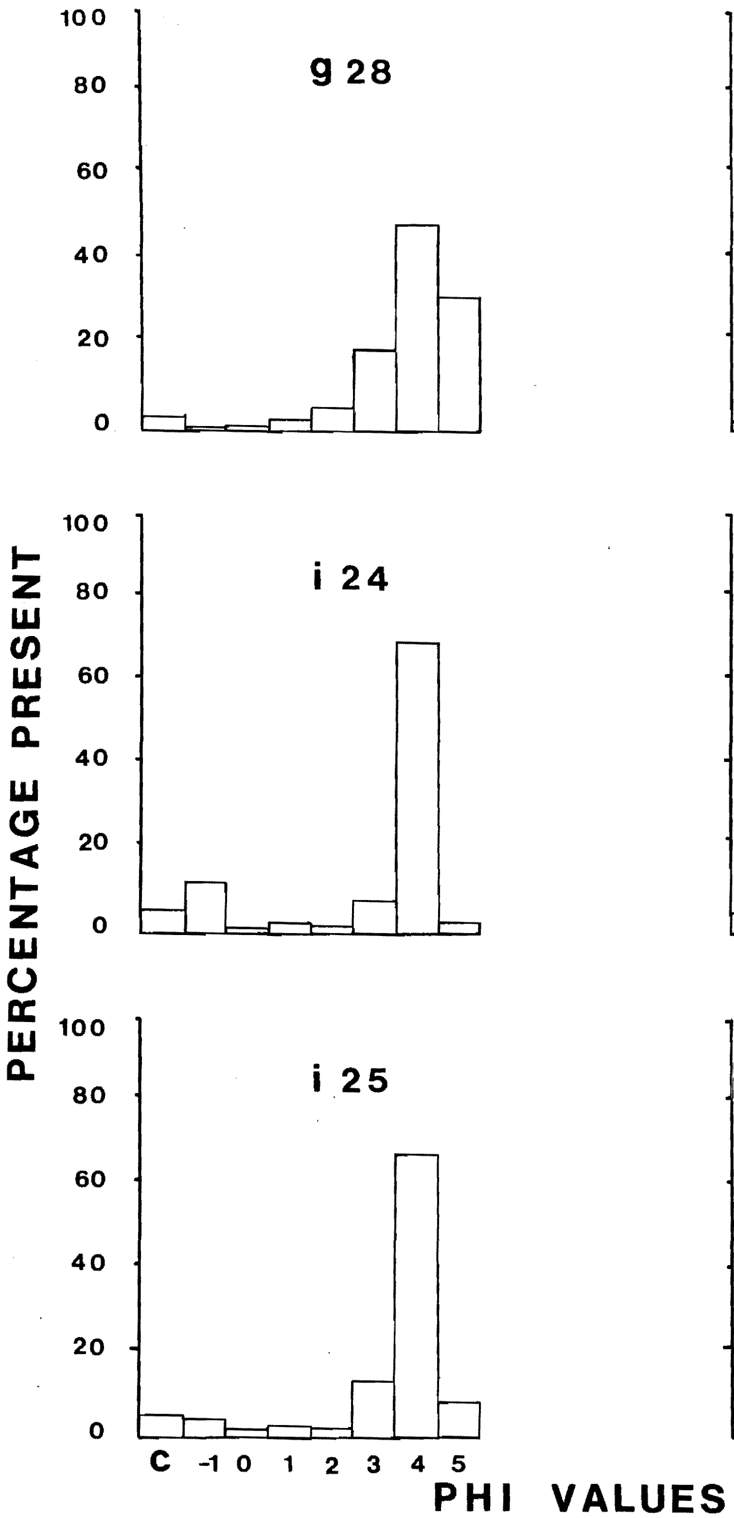

g 28
j 24
i 24
i 23
i 25
j 21
100
80
60
40
20
0
PERCENTAGE PRESENT
C -1 0 1 2 3 4 5
-1 0 1 2 3 4 5+
PHI VALUES

FIGURE 13.6

Size class distributions at sites g22, h21, h18, g23, h20, and f23.

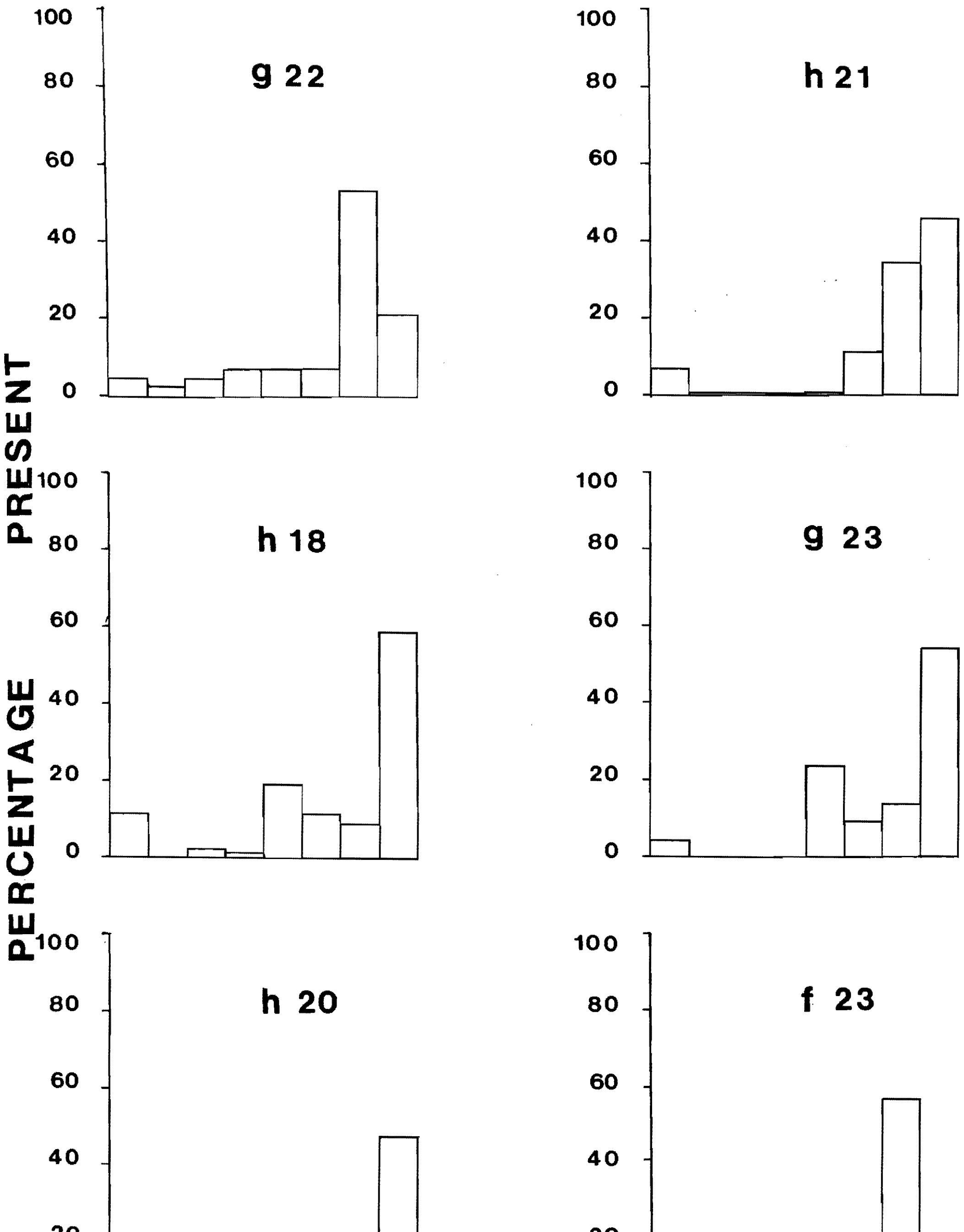
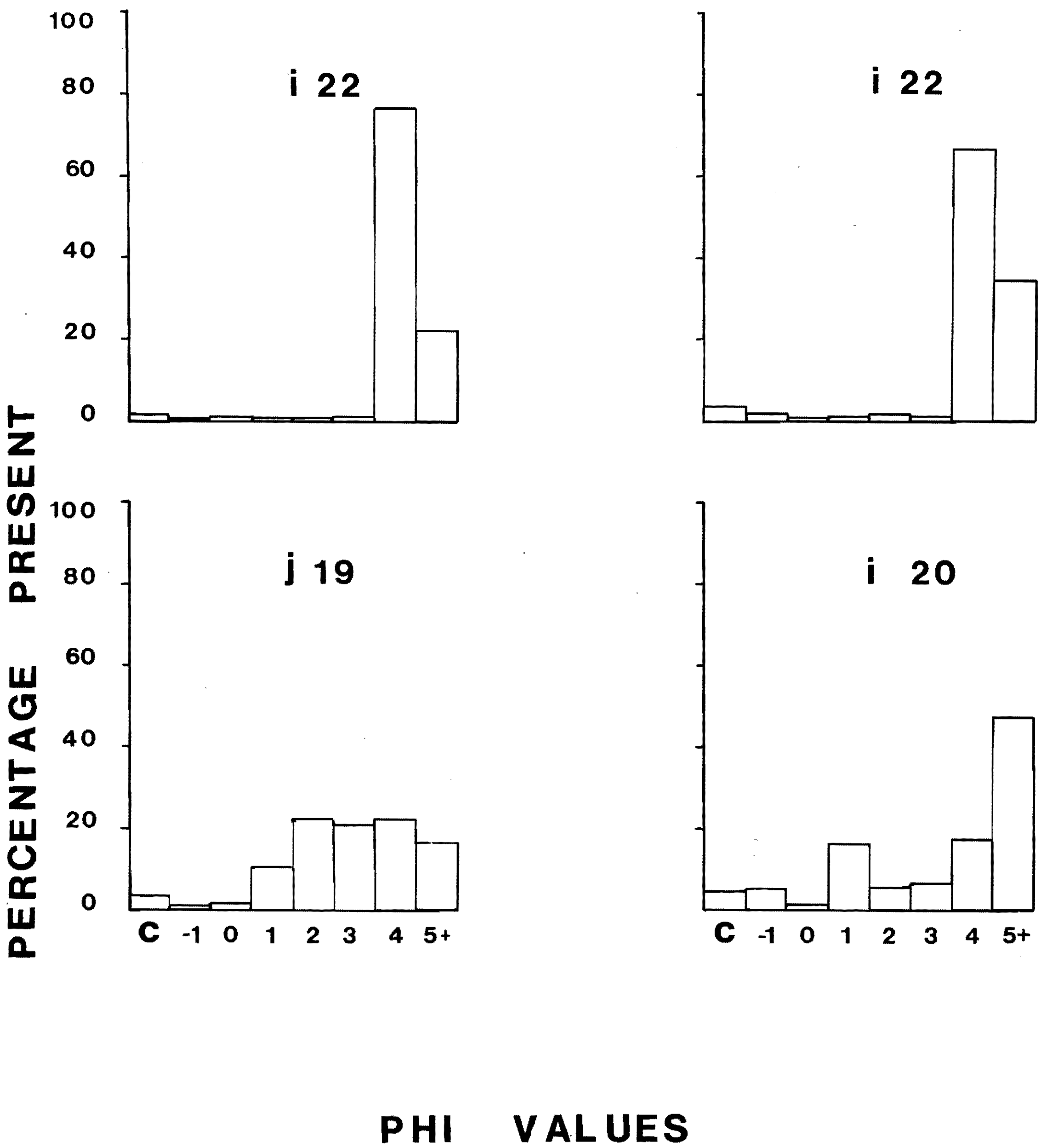

g 22
h 21
h 18
g 23
h 20
f 23
PERCENTAGE PRESENT
PHI VALUES
C -1 0 1 2 3 4 5+
0 20 40 60 80 100

FIGURE 13.7

Size class distributions at sites i22, i22, j19, and i20.


i 22
i 22
j 19
i 20
100
80
60
40
20
0
C -1 0 1 2 3 4 5+
PERCENTAGE PRESENT
PHI VALUES

SECTION 3

FAUNA

3.1 INTRODUCTION

Biogeographically,Lyttelton Harbour lies in the Cookian province of New Zealand, comprising the Southern part of the North Island and the northern half of the South Island. It is a mixed cold and warm water region with the subtropical convergence oscillating seasonally about the latitude of Kaikoura.

3.2 The benthic environment in the harbour

Mention has been made of the disturbance of sediment in the upper harbour areas by swells with a wave base of 3-4 fathoms (Section 1.2.2). Under extreme conditions most of the water in Governors Bay, from a depth of 4 metres to the shore, resembles liquid mud. The only exception to this is where currents are flowing into the bay along the northern coast of Quail Island. Elsewhere in the middle harbour the visibility averages about 0.5 metres, indicating a constant moderately high suspended sediment load. Under normal conditions this improves to about one metre visibility towards the heads.

3.3 Hydrology

There is a large annual range of temperatures in the harbour. In 1970 the variation was from 7°C to 19°C (see Fig.3). There are also quite large local variations, particularly in Governors and Charteris Bays where up to 400 acres of mud flat may be exposed at low tide. The mud is heated in sunny weather and temperatures of

25°C are common. There is free interchange of water with the open sea and salinities throughout the harbour are constant all year.

3.4 Species List

Below is a list of all species found during the sampling period.

PHYLUM MOLLUSCA

Class Amphinura

Acanthochiton zelandicus zelandicus (Quoy and Gaimard, 1835)
Cryptoconchus porosus Burrow, 1815
Terenochiton inquinatus (Reeve, 1847)

Class Gasteropoda

Alcithoe arabica (Gmelin, 1791)
Amphibola crenata (Gmelin, 1791)
Austrofusus glans (Roeding, 1798)
Austromitra rubiginosa (Hutton, 1873)
Chemnitzia zelandica zelandica (Hutton, 1873)
Cominella glandiformis (Reeve, 1847)
Maoricolpus roseus roseus (Quoy and Gaimard, 1834)
Maurea punctulata punctulata (Martyn, 1784)
Micrelenchus huttoni (Smith, 1876)
Notoacmea daedala (Suter, 1907)
Zemitrella stephanophora (Suter, 1908)
Penion mandarinus (Duclos, 1831)
Risselopsis varia carinata (Hutton, 1873)
Sigapatella novaezelandiae Lesson, 1830
Trochus tiaratus Quoy and Gaimard, 1834
Zeacolpus vittatus (Hutton, 1873)

Xymene plebejus (Hutton, 1873)
Zeatrophon ambiguus (Philippi, 1844)
Zegalerus tenuis (Gray, 1867)

Class Pelecypoda

Amphidesma australe australe (Gmelin, 1791)
Amphidesma subtriangulatum (Wood, 1828)
Atrina zelandica (Gray, 1835)
Chlamys gemmulata radiata (Hutton, 1873)
Chione stutchburyi (Gray, 1828)
Gari lineolata (Gray, 1835)
Mariomactra ordinaria (Smith, 1898)
Myadora striata (Quoy and Gaimard, 1835)
Mytilus edulis aoteanus Powell, 1958
Nucula hartvigiana Pfeiffer, 1864
Ostrea heffordi Finlay, 1928
Panopea zelandica (Quoy and Gaimard, 1835)
Paphirus largillierti (Philippi, 1849)
Perna canaliculus (Gmelin, 1791)
Ryenella impacta (Hermann, 1782)
Spisula aequilateralis (Deshayes, 1854)
Tawera spissa (Deshayes, 1835)
Zenatia acinaces (Quoy and Gaimard, 1835)

Class Cephalopoda

Octopus maorum, Hutton 1880
Sepioloidea pacifica (Kirk, 1882)

PHYLUM ECHINODERMATA

Class Asteroidea

Coscinasteria calamaria (Gray, 1832)

Crossaster japonicus
Allostichaster insignis Farquhar.
Asterina regularis Verrill 1875

Class Ophiuroidea

Ophiomyxa brevirima Clark.
Amphibolis squamata (Delle Chiaje.

Class Holothuroidea

Paracaudina coriacia Heding 1931
Cucumaria alba (Hutton 1872)

PHYLUM CHORDATA

Class Ascidiacia
Acidia aspersa (Mueller.)
Pyura pachydermatina Herdman
Ciona intestinalis Savigny
Pyura pulla Hartmeyer
Pyura suteri Sluiter

PHYLUM NEMERTEA

unidentified nemertine

PHYLUM PRIAPULIDA

Halicryptus sp.

PHYLUM ARTHROPODA

Class Crustacea
sub class Cirripedia
Balanus decorus
sub class Malacostracea
order Pericarida

sub order Mysidacea

Mysis sp.

sub order Isopoda

Conodophilus lineatus Miers 1876

Isoclodus armatus (Milne-Edwards, 1840)

Amphiroides falcifer

sub order Amphipoda

Ampelisca chiltoni Stebbing, 1888

Corophium acherusicum Costa, 1857

Haplocheira barbimana Thomson, 1879

Paradexamine laevis Thomson, 1919

Paradexamine pacifica Thomson, 1879

Parhalimedon sp.

Proharpinia stephenseni Schellenberg, 1931

Caprella sp.

? Class Arachnida

order Pantopoda

Achelia dohrni Stock,

Achelia variabilis Ault

order Eucarida

sub order Decapoda

Cancer novaezelandiae (Jacquinot and Lucas, 1853)

Elamena quoyi (Milne-Edwards, 1853)

Halicarcinus whitei (Miers, 1876)

Hemiplax hirtipes Heller, 1865

Nectocarcinus antarcticus (Jacquinot and Lucas, 1853)

Ovalipes bipustulentus Milne-Edwards, 1861

Notomithrax minor (Filhol, 1885)

Petrolisthes elongatus (Milne-Edwards, 1843)

Pontophilus australis (Thompson, 1879)

PHYLUM BRACHIOPODA

Terebratella inconspicua (Sowerby, 1861)

PHYLUM ANNELIDA

Class Polychaeta

Aglaophamus macrura (Schmarda, 1861)
Aglaophamus verrilli (McIntosh, 1885)
Amphictes sp.
Branchiomma cingulata Grube 1870
Clymene insecta Ehlers, 1905
Euphione squamosa (Quatrefages, 1865)
Euphione sp.
Glycera lamellipodia Knox 1960
Harmothoe preclara (Haswell, 1883)
Harmothoe spinosa Kinberg, 1855
Leanira laevis McIntosh 1885
Lepidonotus polychromus Schmarda 1861
Lumbrinereis sp. (nov.sp.)
Nereis falcaria (Willey, 1905)
Nicolea chilensis (Schmarda, 1861)
Nicon aestuariensis Knox 1951
Owenia fusiformis Delle Chiaje 1842
Pectinaria antipoda (Schmarda, 1861)
Perinereis nuntia (Savigny) *var vallata* (Grube 18
Platynereis australis (Schmarda, 1861)
Prionospio pinnata Ehlers 1961
Sternaspis scutata (Renier, 1807)
Terebella haplochaeta (Ehlers, 1904)
Terebellides stroemi Sars 1835
Tharyx sp.

Travisia olens Ehlers *var novae zealandiae*, Benham 1927

Class Sipulculoidea

Dendrostomum huttoni Benham 1904

Golfingia cantabriensis Edmonds 1960

PHYLUM COELENTRATA

Class Hydrozoa

Anthopleura aureoradiata Stucky 1909

Edwardsia tricolour Stucky 1908

Class Actinozoa

order Alcyonaria

Virgularia gracillima Koelliker, 1880

Class Scyphozoa

Obelia sp.

PHYLUM ECTOPROCTA

Class Gymnolaemata

Cellepora pumicosa

Retepora sp.

3.5 Faunal assemblages related to local conditions

The most striking of these is the very large bed of *Chione stutchburyi* which extends out about 400 metres along the north and north-western coasts of Quail Island. In this area, they cover the entire seafloor, 2 or 3 animals thick with a biomass exceeding 10,000 grams per square metre in many cases. Associated with this bed is a much smaller population of *Myadora striata* in densities of approximately 8 per square metre.

There are very few juveniles in this area, but between the end of the main bed and the low water mark in Head of the Bay (see Fig.2), there are concentrations of juveniles of both species. It appears that neither species can grow in the upper harbour beyond the 9 millimetre size outside the main bed although impossible to prove at this stage. Elsewhere in the harbour both *Chione* and *Myadora* have a scattered distribution. They are relatively abundant in the sandy regions down the middle of the harbour, to the north of the shipping channel.

The bulk of Governors Bay and Head of the Bay is very muddy with a well sorted glutinous sediment. Anaerobic conditions, as judged by the development of a sulphide layer, prevail below two centimetres. The principal animal group here consists of three species, a small burrowing crab, *Hemiplax hirtipes*, a pennatulid, *Virgularia gracillima*, and an asteroid *Asterina regularis*. Both *Hemiplax* and *Asterina* feed as scavengers on the mud surface which is rich in organic material. Occasionally present are *Pontophilus australis*, a common shrimp that moves around the harbour in dense shoals, and *Nectocaranus antarcticus*, a large predatory crab.

Hemiplax hirtipes is the principal food of the area's two most abundant fish, the Puffer *Uranostoma richei* (Freminville) (Habib, 1971) and the Sand Flounder, *Rhombosolea plebia*, both of which are very abundant in the bays.

Overall biomass is very low in the muddy areas of the harbour averaging 5 - 10 grams per square metre. There are remarkably few polychaetes and no large gasteropods until the pulmonate Amphibola crenata appears near the low tide mark. In Fig. 14, the fauna present has been divided into the three classes; filter feeders, detrital feeders, and predators. It shows a great predominance of detrital feeders both in numbers of individuals present and in biomass.

There is an obvious lack of filter feeders, presumably since the suspended material in the water would clog the filtering apparatus of such animals.

Moving down the harbour to the sandy mud areas east of Quail Island, the biomass and diversity increases tremendously, the former averaging about 300 grams per square metre.

Reference to the maps of the areas of occurrence of the indicator species, shows that there is a much greater proportion found in areas designated sandy mud, Fig. 8, than the surrounding mud areas.

3.6 The effects of algal growth on the benthos

A red filamentous algae, Polysiphonia sp., grows in large masses in the upper harbour areas between late November and late April each year. This is the only alga detected in any quantity away from rocky regions. The density of the weed may be judged by the fact that it is possible to fill an otter trawl with hundreds of kilograms of the material with a short trawl, (G. Habib, pers. comm.).

The densest area of growth is to the north of Quail Island except for a six hundred metre strip immediately offshore from Quail Island that generally remains clear. The density then decreases until the

FIGURE 14.

Composition of fauna in, from left, sandy, muddy sand, and muddy substrates.

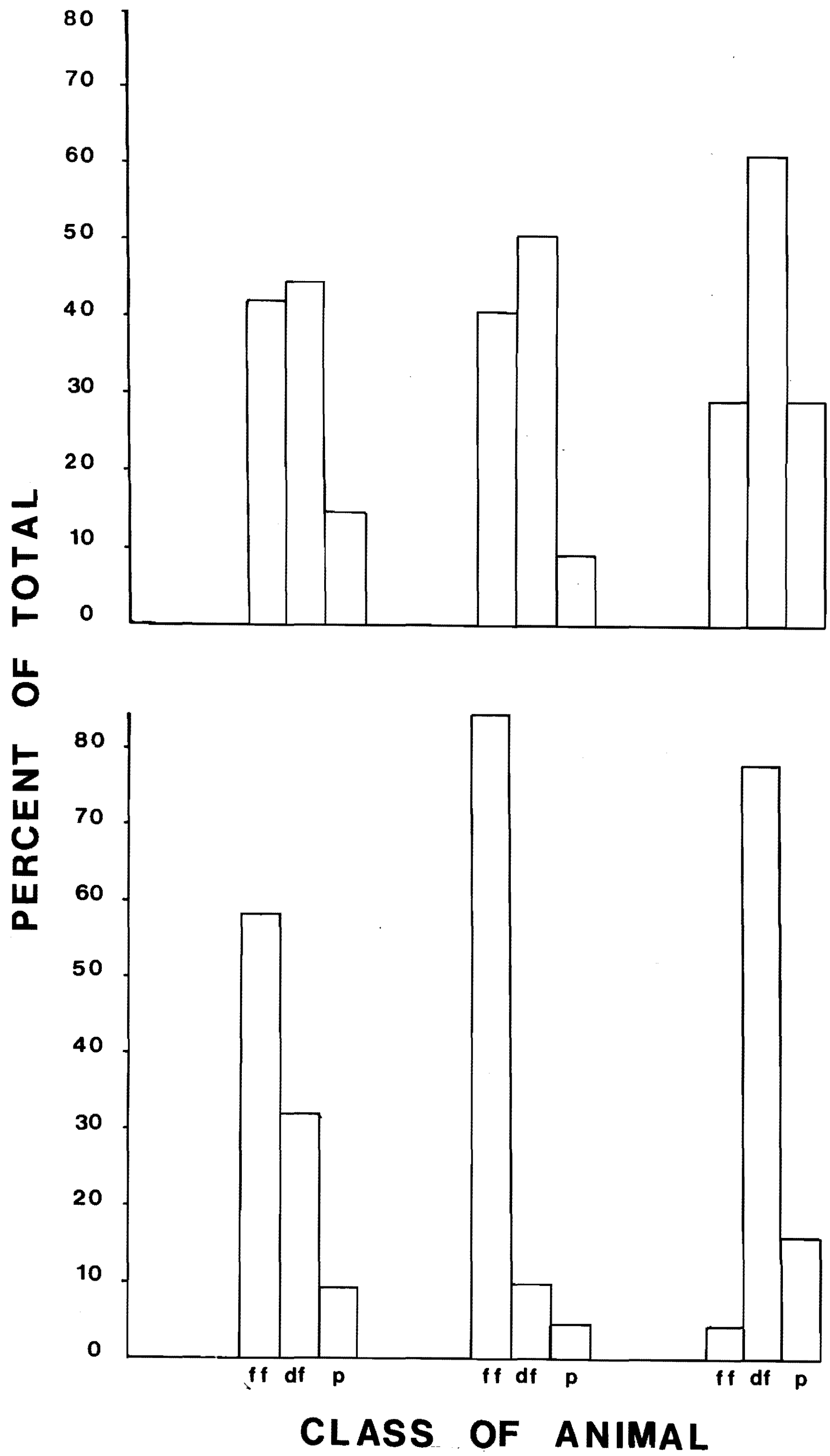
Top; by species

Bottom ; by biomass

ff = filter feeder

df = detritus feeder

p = predator


PERCENT OF TOTAL
80
70
60
50
40
30
20
10
0
80
70
60
50
40
30
20
10
0
ff df p
ff df p
ff df p
CLASS OF ANIMAL

alga disappears before the opposite coast is reached. Algae are also present to the West of Quail Island and to a smaller extent in Charteris Bay. It seems likely that the water around the shores of Quail Island is kept clear of the algae by the tidal currents as described in Section 2.

3.6.1 Effects on the substrate

The most important effect of the alga on the sediments in the regions concerned is that of stabilization. Being a mud it is easily transported but also readily compacted if protected from current and wave action. The compaction was particularly noticeable when sampling with a Petersen grab where the depth of penetration was less than half that where there was no weed cover. There was no evidence that the alga was rooted in the mud. All undisturbed samples taken showed a tangled mat of filaments with no attachment points to the mud.

3.6.2 Effects on the fauna

There is a dramatic change in numbers of animals, accompanied by a few new animals, in what was formerly a fairly sterile muddy area, with the growth of the alga. Table 1 shows a comparison of four sites samples with and without the algal mat. The number shown are average values for fauna at sides I12, H11, H10, and H8 sampled before the algae appeared in bulk in October 1969, and during the height of the bloom in March - April 1970. As a control, sampling in similar muddy areas with no weed showed no significant change in species composition over the period October - April.

Species	Sites Affected By Alga		Sites Not Affected By Alga
	Oct '69 Mean Numbers Without Alga	March '70 Mean Numbers With Alga	March '70 Mean Numbers
Hemiplax hirtipes	14	12	11
Isocladus armatus	2	16	1
Amphiroides falcifer	0	6	1
Paramithrax minor	1	4	2
Virgularia gracillima	29	1	18
Sepioloidea pacifica	0	3	0
Micrelenchus huttoni	1	23	3
Pontophilus australis	12	16	14
Musculus impacta	1	7	5
Ophiomyxa brevirima	1	11	3
Asterina regularis	3	4	4
Xymene plebejus	2	9	3
Zeacolpus vittatus	2	3	0
Myadora striata	4	1	2
Coscinasterias calamaria	0	3	1
Gobid bully	0	3	0
Austromitra rubiginosum	1	3	1

Table (1) Comparisons of mean numbers of animals at four sites with and without algal cover

The normal inhabitants of the muddy area include the burrowing crab, Hemiplax hirtipes, pennatulid Virgularia gracillima, bivalve Myadora striata, and asteroid Asterina regularia. With the advent of the alga, the number of Virgularia dropped drastically while those of Hemiplax were barely affected. Likewise Asterina numbers remained constant but those of Myadora dropped by a factor of four.

There were very large increases in the numbers of herbivorous gasteropods Micrelenchus huttoni, the brittle star, Ophiomyxa brevirima, and the small isopod Isocladus armatus. Smaller increases were recorded with the masking crab Notomithrax ~~Paramythrax~~ minor, the squid, Sepioloidia pacifica, mussel Musculus impacta, the gasteropods Xymene plebejus, and Austromitra rubiginosum, the asteroid Coscinasterias calamaria and a small unidentified bully. An increase was also noticed in the numbers of Amphiroides falcifer. This is a highly modified and cryptically coloured isopod whose long spindly frame and red colour makes it almost invisible among the filaments of the alga.

3.7 Notes on indicator species.

(1) Pontophilus australis (Fig 15.1)

This species, a small shrimp, shows marked seasonal changes in abundance. It is most abundant between November and April. The sudden appearance suggests a migration but there is at present no direct supporting evidence.

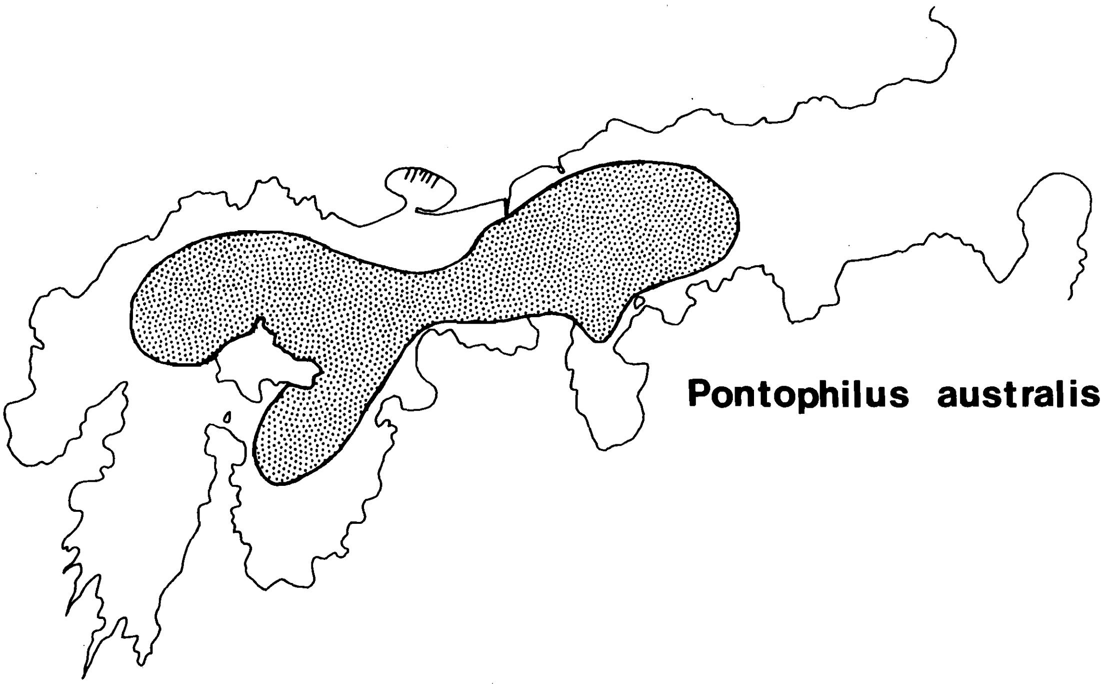
The patchy catches that were often experienced may have been indicative of shoaling in a manner similar to some types of prawn. Generally they were restricted

FIG 15.1

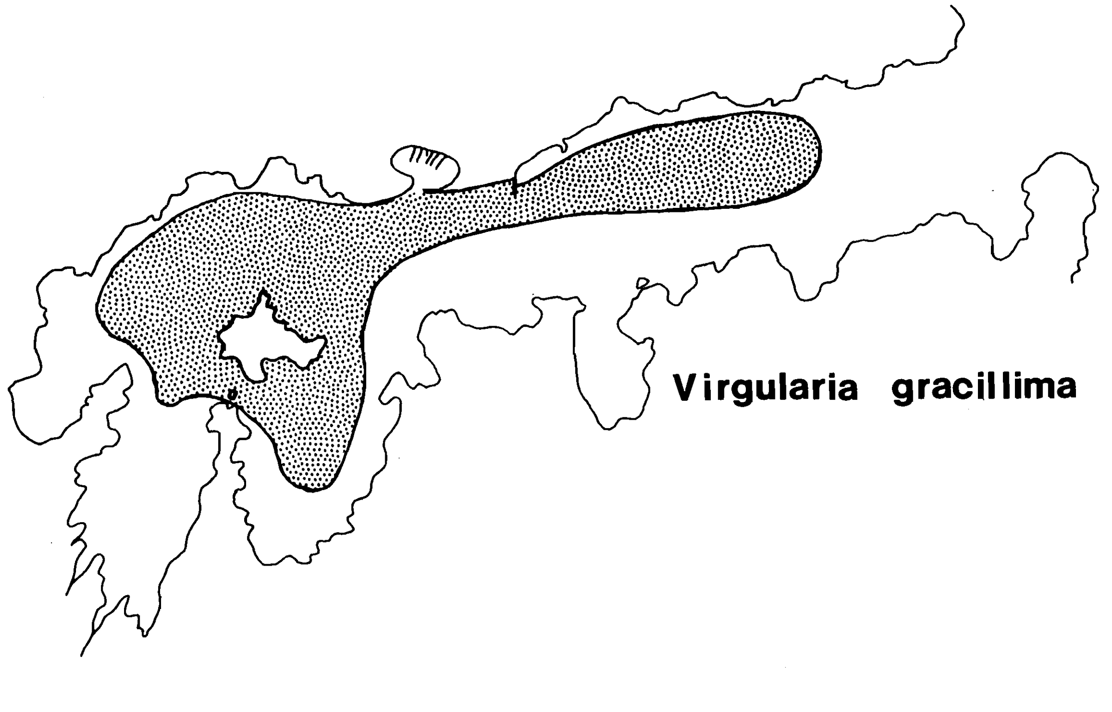
The distribution of *Pontophilus australis* in Lyttelton Harbour

FIG 15.2

The distribution of *Virgularia gracillima* in Lyttelton Harbour



Pontophilus australis



Virgularia gracillima

to the middle and upper harbour and were more common in the muddy regions but were also caught occasionally in the sandy parts. They appeared to be restricted to areas covered by at least a metre of water at low tide and did not penetrate far into Purau. Densities at the height of their presence rose to over 400 per square metre. There was a slight increase in numbers where there was weed cover but insufficient samples were taken to determine if this was a significant correlation. Fig 15.1 shows the distribution on a presence or absence basis.

(2) *Virgularia gracillima* (Fig 15.2)

This sedentary pennatulid is very widespread in Lyttelton Harbour but is restricted almost entirely to the muddy regions. Generally it was absent from the shallow portions of Governors Bay and Head of the Bay possibly because of the extreme turbidity of the water in rough conditions. There is a tremendous decrease in density with the growth of weed cover. Table 1. shows an overall decrease from 29 per square metre to 1 per square metre at the peak of algal growth. *Virgularia* was also found abundantly in dredged areas near the shipping channel suggesting a fairly rapid growth rate since these deepened portions are regularly attended to (Captain Chrisp pers.comm.). *Virgularia* was also found in sediments in the harbour that were heavily polluted with oils and other waste materials. The only areas where *Virgularia* was found other than on mud was around the shores of Quail Island where the incoming tidal current diverges.

(3) Chione stutchburyi (Fig 15.3)

This cockle is common throughout New Zealand in sheltered inlets and on mudflats (Morton and Miller, 1970, Ralph and Yaldwyn, 1956). It usually grows in large beds where conditions suit its establishment. This is the case in Lyttelton Harbour with very dense beds, almost pure stands of Chione, are found around the coasts of Quail Island and extending eastward from Quail Island along the path of the flood tide. Smaller patches were found elsewhere in the middle harbour but none were dense and the individual animals were smaller. To the west and northwest of the Quail Island beds, and extending to the low water mark, there was a region of juvenile Chione. They reached a maximum diameter of 9 millimetres, most being less than this. It appeared that they could not survive above this size outside the main bed. Presumably spat fall is very widespread over the upper harbour and initially juveniles survive and grow outside the main bed. Conditions for survival past this stage must be met only where the present population is found. There does not seem to be any evidence of migration of Chione within the harbour.

(4) Myadora striata (Fig 15.3)

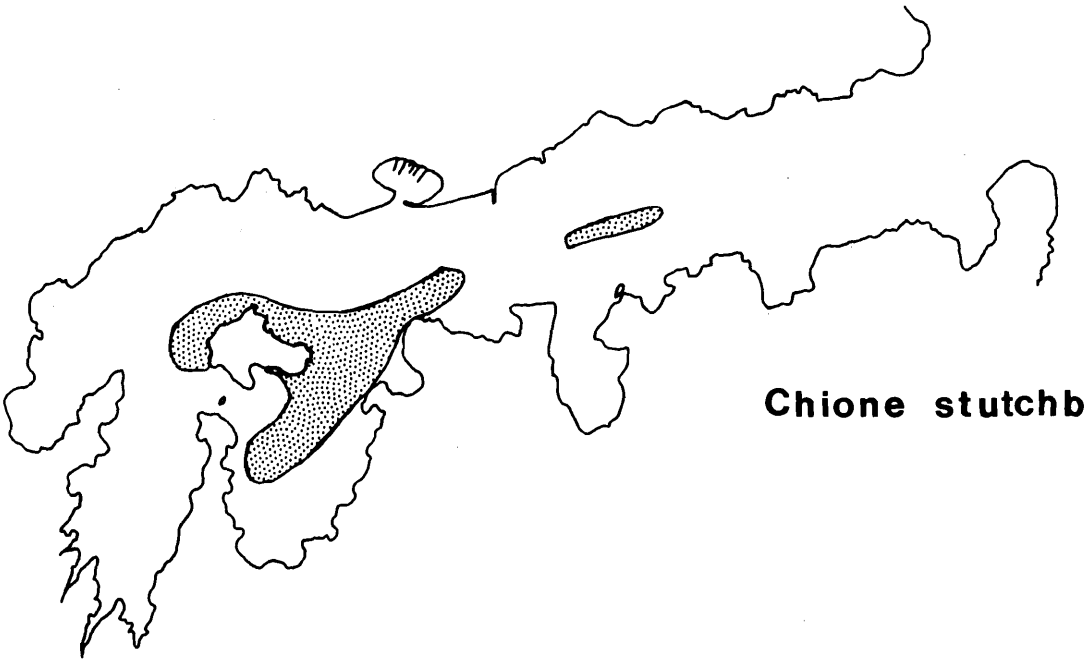
This species show a similar distribution trend to that of Chione. Myadora does penetrate the Chione bed but reaches its maximum around the perimeter of the beds. Comparing Fig 15.3 and Fig 15.4 it may be seen that Myadora penetrates slightly further out into the muddier sediments from the shores of Quail Island. The distribution down the middle harbour again was basically similar to that of Chione but the impression was that Myadora showed a greater tolerance of fine

FIG 15.3

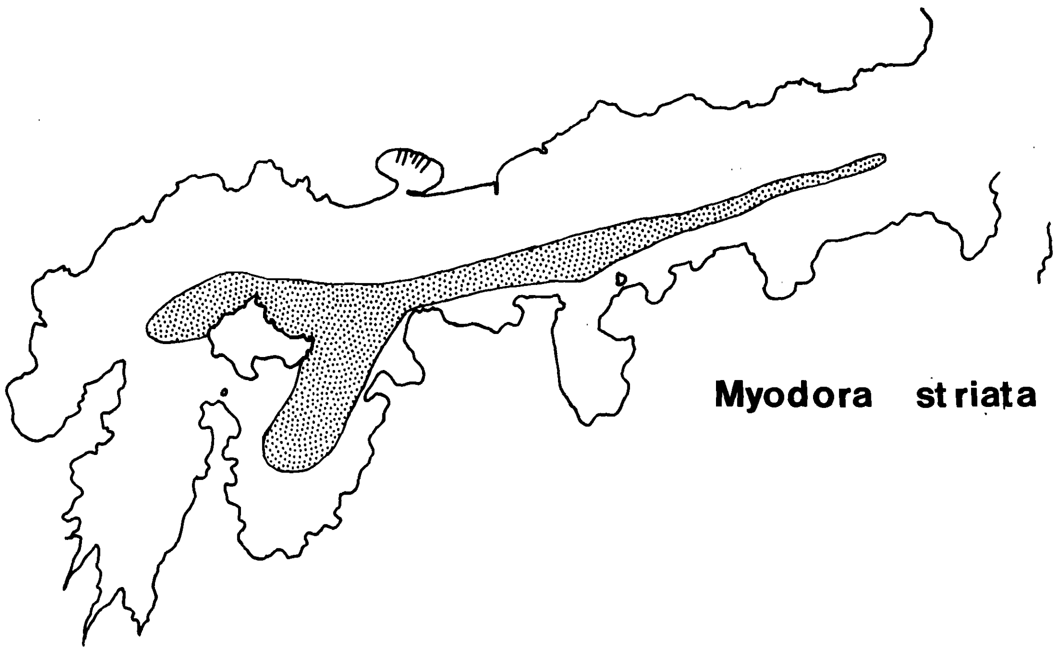
The distribution of _Chione stutchburyi_ in Lyttelton Harbour.

FIG 15.4

The distribution of _Myadora striata_ in Lyttelton Harbour



Chione stutchburyi



Myodora striata

sediments. This was reinforced by finding Myadora among the dredge dumpings.

Juvenile Myadora were found associated with juvenile Chione in Governors Bay outside the beds of mature animals. As with Chione there is a degree of muddiness that only the young stages can withstand and all adults were confined to the sandy and coarse sand areas of the harbour.

(5) Ophiomyxa brevirima (Fig 15.5)

A small brittle star, Ophiomyxa is not very abundant in the harbour, being mainly restricted to small regions in the upper harbour, particularly where the substrate is well compacted. The only periods of concentration come when the alga growth is at a maximum. The average density increased from 1 to 11 per square metre, probably by migration in from surrounding areas. This species is a detrital feeder as all guts that were examined were filled with sediment. The high organic content in the regions occupied by Ophiomyxa could provide a ready supply of nutrient.

(6) Pectinaria antipoda (Fig 15.6)

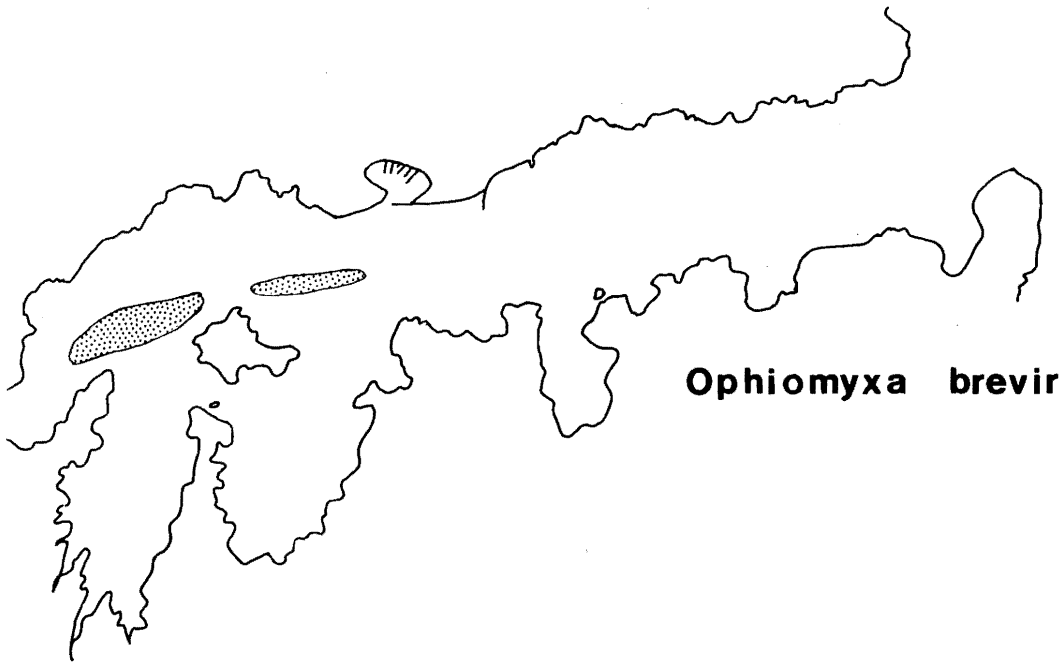
Pectinaria, a tube dwelling polychaete, lives in a cylinder of sand grains held together with a hard reddish cement. The grains in the case of Lyttelton Harbour Pectinaria seem to be mainly the volcanic mineral obsidian, derived from decayed lava flows. Pectinaria has a very extensive range covering most of the sandy areas and is very abundant to the north west of Ripapa Island. A small concentration was found along the relatively sandy western side of Purau Bay. Is also extended into the Chione beds but only to the

FIG 15.5

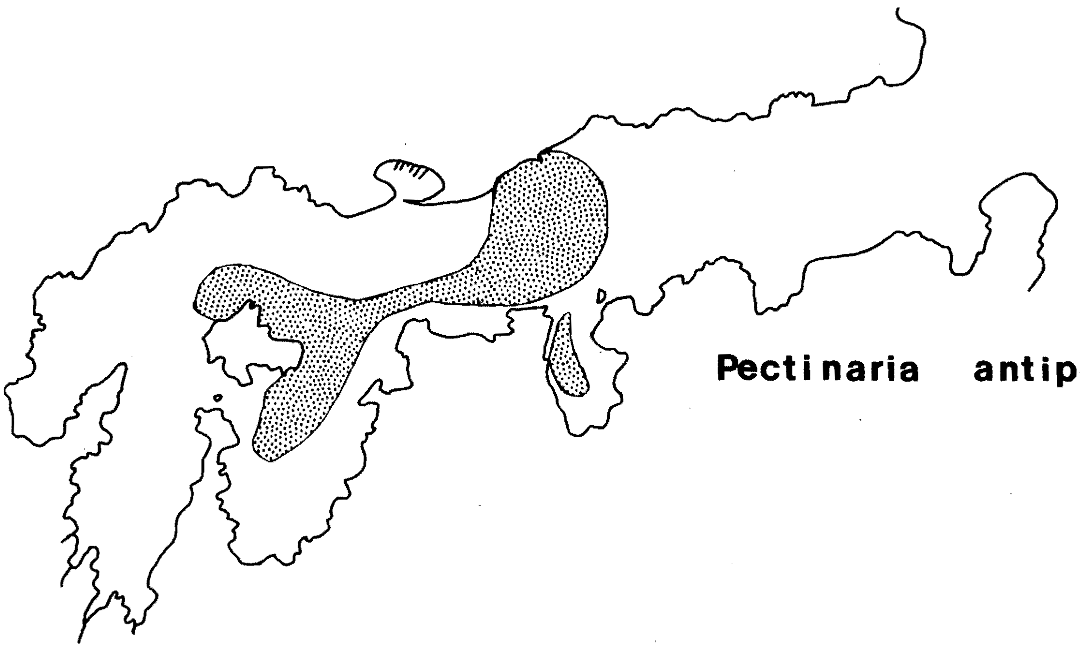
The distribution of Ophiomyxa brevirima in Lyttelton Harbour.

FIG 15.6

The distribution of Pectinaria antipoda in Lyttelton Harbour



Ophiomyxa brevirima



Pectinaria antipoda

extent of 2 or 3 per square metre. A local concentration was apparent in Charteris Bay, south east of Quail Island where the diverging flood tide current had maintained a sandy region.

Pectinaria was chosen as an indicator species representative of the polychaeta because of its robust tube which allowed it to be pushed around the surface of a sieve without being broken up. Being a detrital feeder Pectinaria did not exist in the coarse sand areas around the mouth of Purau Bay where the organic carbon content was very low and detrital feeding would not be a viable proposition.

(7) Halicarcinus whitei (Fig 15.7)

Small spider crabs such as Halicarcinus are a favourite fish food. For this reason Halicarcinus was always found associated with cover such as empty mussel shells, or small rocks, and among the Chione beds. It was widely spread over the sandy regions, particularly where there were deposits of empty shells. It was also more abundant around the reef projecting north from Ripapa Island. The same applied at the rocky eastern tip of Quail Island. As with most of the crab fauna of Lyttelton Harbour Halicarcinus was confined to the sandy and sandy mud portions. But it was found over the shipping channel, suggesting considerable mobility and adaptability. Halicarcinus was not found among the algal growth in the upper harbour.

(8) Austromitra rubiginosum (Fig 15.8)

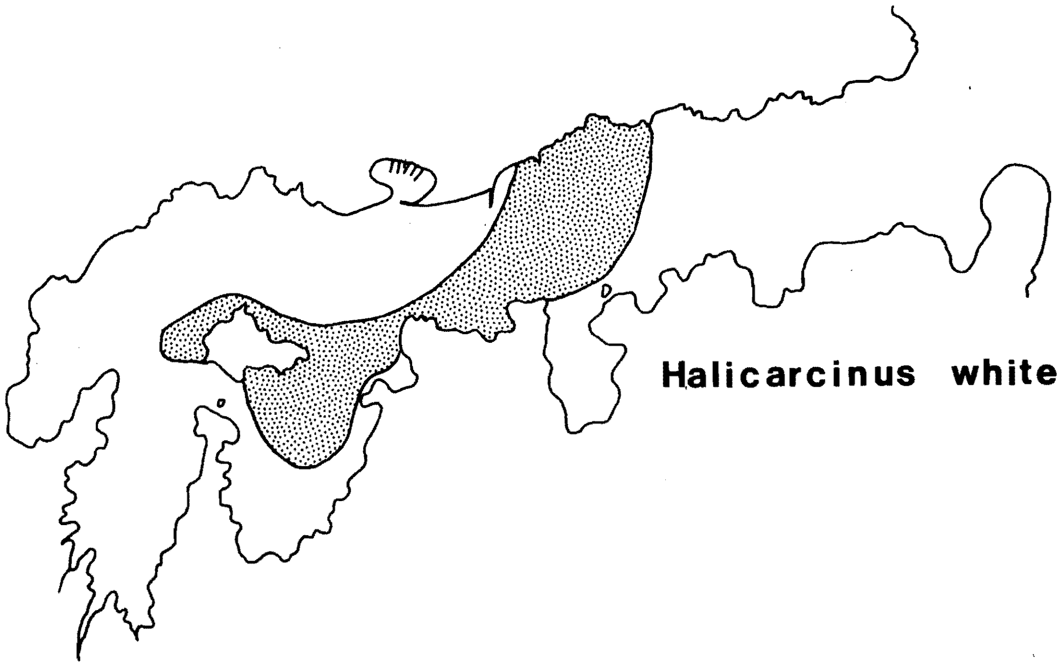
This small gasteropod is very widespread around the New Zealand coasts. Within the harbour it is common over the coarse and muddy sand areas and penetrates

FIG 15.7

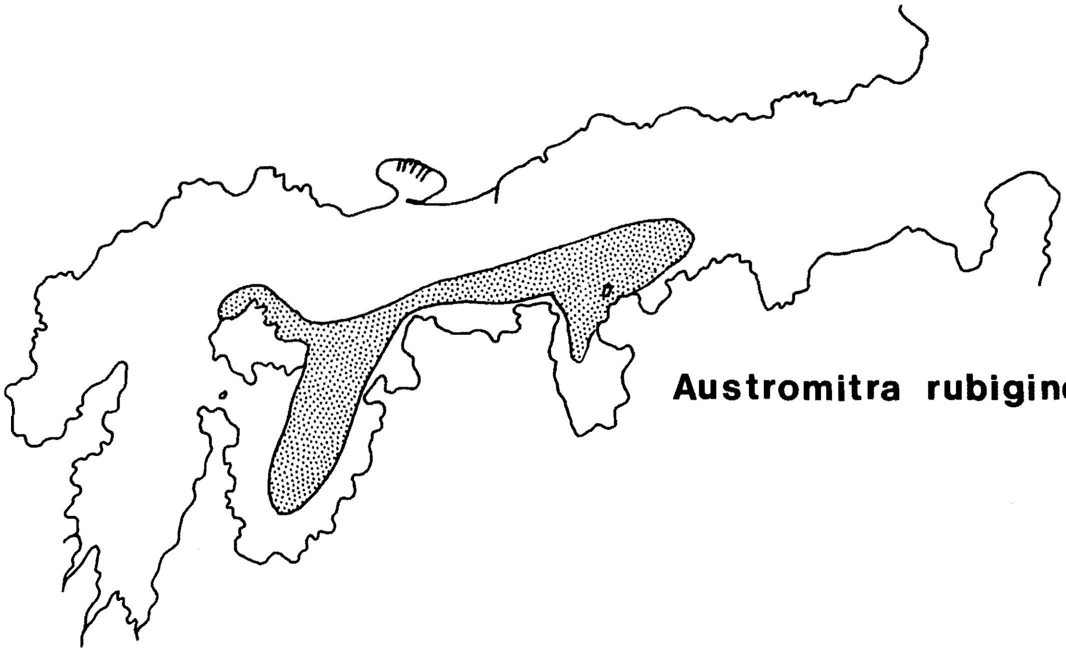
The distribution of *Halicarcinus whitei* in Lyttelton Harbour.

FIG 15.8

The distribution of *Austromitra rubiginosum* in Lyttelton Harbour.



Halicarcinus whitei



Austromitra rubiginosum

well into Charteris Bay. It also penetrates a short distance into the muddy sediments of Purau Bay. As with *Halicarcinus* there are concentrations about the reefs at Ripapa Island and Quail Island. But unlike *Halicarcinus*, *Austromitra* does not extend over the dredged channel and the map shows the sharp cut off at the edge of the dredged region. *Austromitra* is present in very small numbers among the *Chione* beds but does not extend out into the muddy middle harbour. There may be a slight correlation between the appearance of *Austromitra* and the growth of red alga. This is suggested in Table 1 but not possible to prove at this stage. There is a very large number of empty *Austromitra* shells off the mouth of Purau Bay that may have been transported by currents from the reef off Ripapa Island.

(9) *Zeacolpus vittatus* (Fig 15.9)

Commonly known as the "turret shell", the gasteropod *Zeacolpus* originally appeared to show a very patchy distribution over much of the harbour. Reconsideration of the material showed that many samples contained only empty shells. Where there were live specimens they constituted on the average only ten percent of the total shells taken. This percentage was arrived at by dissolving the shells away in 1M. hydrochloric acid and relating the number of carcasses left to the original number of apparently occupied shells. The final pattern showed a bias towards the sandy sediments, and a smaller number in the coarse sand regions. There was a deep penetration into Purau Bay, almost to the low tide mark. In Purau *Zeacolpus* were surviving in very muddy conditions. There was a scattered occurrence across the shipping

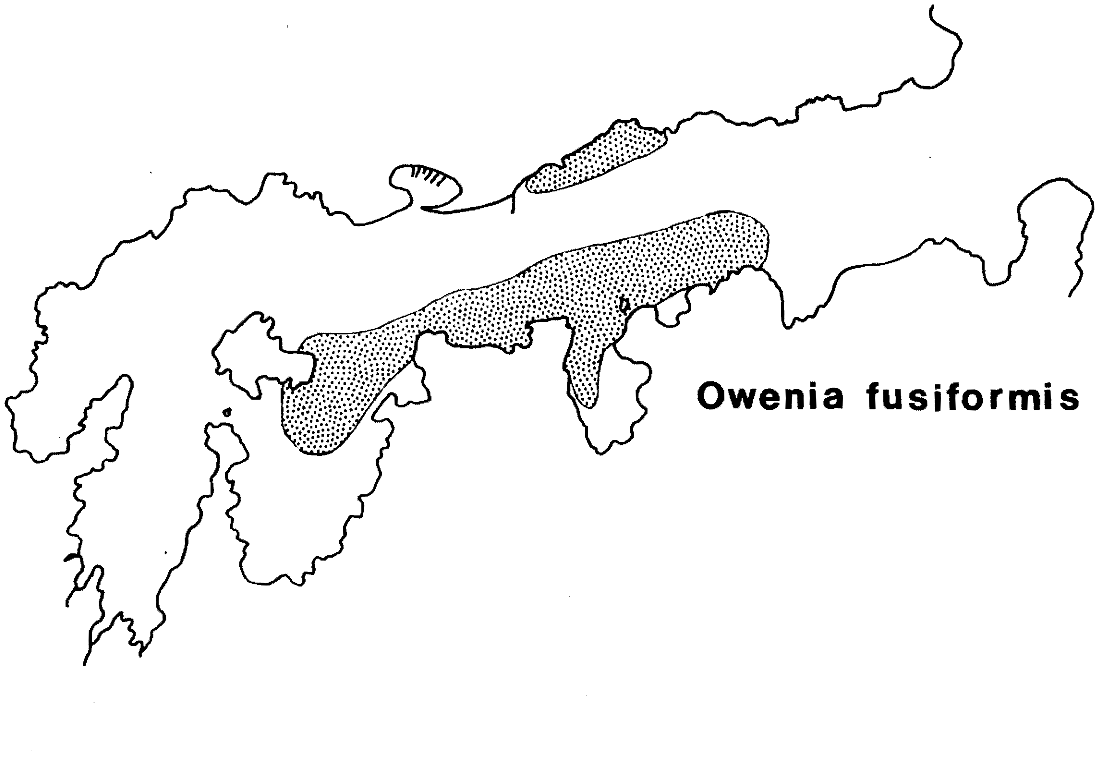
FIG 15.9

The distribution of *Zeacolpus vittatus* in Lyttelton Harbour

FIG 15.10

The distribution of *Owenia fusiformis* in Lyttelton Harbour

Zeacolpus vittatus



Owenia fusiformis

channel and a very dense growth directly across the harbour from Ripapa Island. In this assemblage hauls of up to 500 per square metre were taken.

Around the shores of Quail Island *Zeacolpus* avoided the *Chione* beds and was found off the eastern and western tips in moderate numbers. It appeared to be unaffected by the presence of algae, occurring equally in areas of dense and no growth. The empty shells of a similar but much larger form, *Maoricolpus roseus roseus* were found wherever living specimens of *Zeacolpus* were taken. There is the possibility that *Zeacolpus* is taking over the habitat of *Maoricolpus* and displacing it in Lyttelton Harbour. In very few cases was *Zeacolpus* found associated with *Maoricolpus*, the exceptions being in Charteris Bay.

(10) *Owenia fusiformis* (Fig 15.10)

This polychaete lives in a tube composed of coarse shell fragments with the occasional rock particle attached to a parchment-like lining. Its distribution corresponds fairly well to the coarse sand regions where this type of material is available. *Owenia* penetrates into Purau Bay along its western side where there may be stronger current action and larger particles available. It did not extend across the shipping channel or into any of the muddy regions with the exception of a localized population on the northern shore of the harbour opposite Ripapa Island.

(11) *Sepioloidea pacifica* (Fig 15.11)

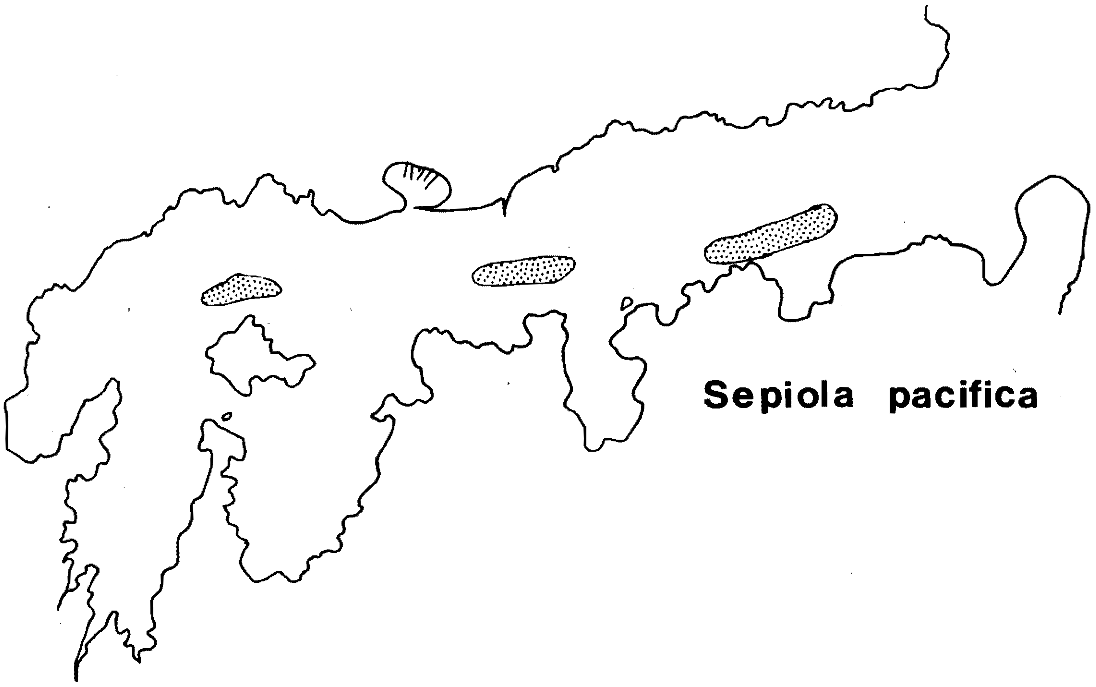
Sepioloidea is a small cuttlefish growing to a length of about three centimetres. It has a very scattered distribution but was caught only in a few

FIG 15.11

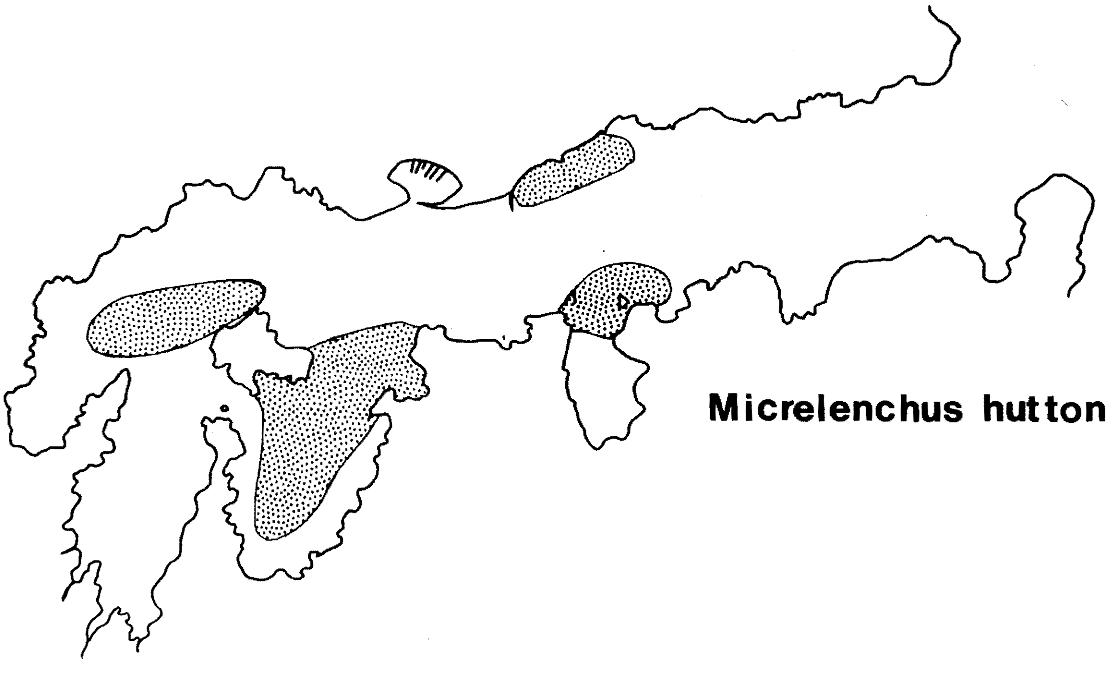
The distribution of *Sepioloidea pacifica* in Lyttelton Harbour

FIG 15.12

The distribution of *Micrelenchus huttoni* in Lyttelton Harbour.



Sepiola pacifica



Micrelenchus huttoni

fairly discrete areas. It is a source of food for the puffer fish, Uranostoma richei, having been found in the stomachs by Habib (1971). Sepioloidea is not present in the upper harbour around Quail Island except when the substrate is covered with algae. Then it occurs to the extent of about three per square metre. This species is found around most of New Zealand's coasts, but more commonly in Northern areas (Suter 1913)

(12) Micrelenchus huttoni (Fig 15.12)

This species, a small blue-black gasteropod shows a very unusual distribution existing in both sandy and muddy sediments but, judging by numbers taken, having a decided preference for muddy regions. It is a herbivore and its distribution is greatly influenced by the appearance of the algal mat in the upper harbour. Table 1 shows an extremely high increase in density of from one per square metre to 23 per square metre. Closer examination of this situation showed that Micrelenchus was using the weed as a food source, for protection, and as a site for breeding.

During the summer, therefore, Micrelenchus has a range that covers most of Governors Bay and almost all of Charteris Bay.

Elsewhere Micrelenchus is much less abundant, with maximum densities of less than 10 per square metre. It is locally abundant around the shores of Ripapa Island and across the mouth of Purau Bay. Directly across the harbour there was found another localized occurrence. In this respect it was very similar to the polychaete Owenia fusiformis. Micrelenchus was not found among the Chione bed.

(13) *Zegelerus tenuis* (Fig 15.13)

Zegelerus, a member of the gasteropod family Calyptraeidae, lives attached to rocks and shells. Suter (1913) considered that they never left the spot on which they first settled. This he deduced from the moulding of the margins of the shell to the rock surface and the variation in the colour of the shell to suit the local environment. In Lyttelton *Zegelerus* is very common on the inside and outside of empty mussel shells around the mouth of Purau, while around the shores of Quail Island this substrate role is fulfilled by the valves of *Chione stutchburyi*.

While *Zegelerus* is generally confined to the sandy regions, these are the only places where objects large enough to provide a secure attachment are found and there is no obvious reason apart from this why it could not be more widespread.

Many specimens of *Zegelerus* have been found brooding eggs in the mantle cavity during December and January. *Zegelerus* is one of the few filter feeding gasteropods.

(14) *Maoricolpus roseus roseus* (Fig 15.14)

There was a very limited area to the south-east of Quail Island where *Maoricolpus* occurred, but elsewhere in the harbour there were extremely large deposits of empty shells. As was mentioned when discussing *Zeacolpus vittatus*, the possibility exists that *Zeacolpus* is taking over the range of *Maoricolpus* in this area. *Maoricolpus* penetrated into the muddy portions of Charteris Bay but was not taken in Governors Bay or Head of the Bay.

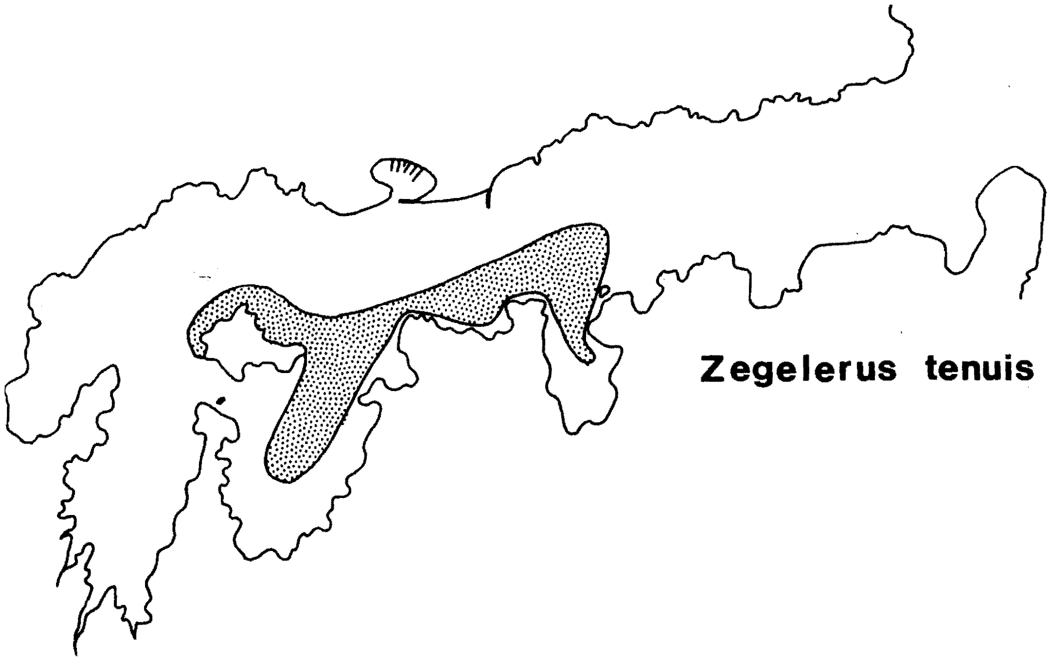
Again as with *Zeacolpus* there were far more empty shells at any collecting site than living ones.

FIG 15.13

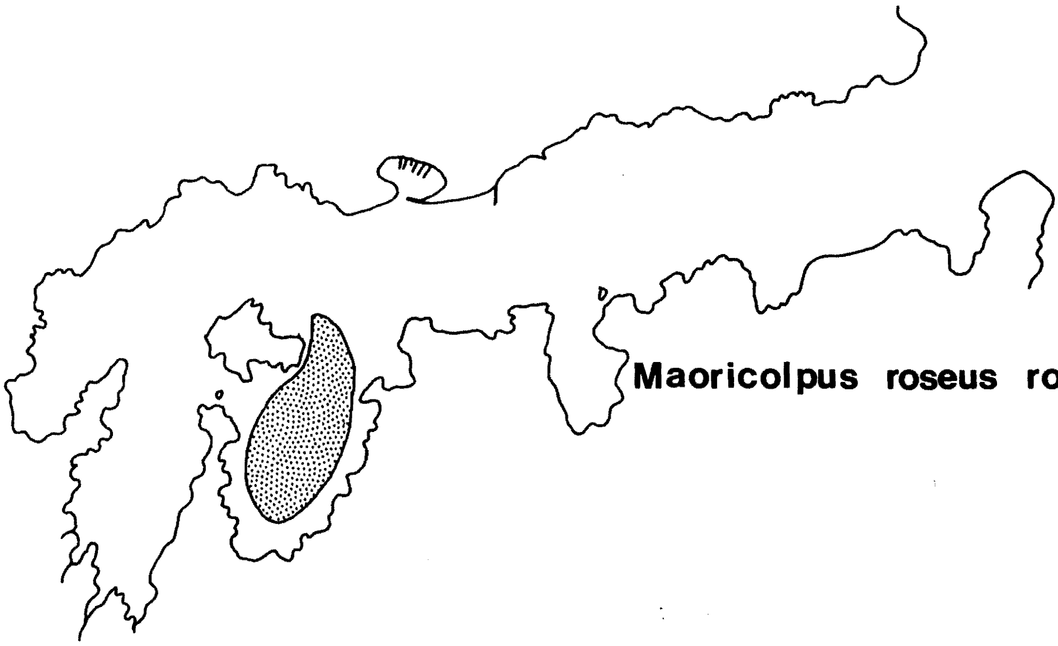
The distribution of _Zegelerus tenuis_ in Lyttelton Harbour.

FIG 15.14

The distribution of _Maoricolpus roseus roseus_ in Lyttelton Harbour.



Zegelerus tenuis



Maoricolpus roseus roseus

(15) *Achelia variabilis* (Fig 15.15)

Although not penetrating into the sandy area off the mouth of Purau Bay *Achelia*, a small pycnogonid, showed a tolerance to a wide range of habitats as it crossed the shipping channel. *Achelia* was most abundant near the northern side of the harbour, (see Fig 15.15) where there was some cover such as low-growing algae and bryozoans. The density of *Achelia* decreased rapidly across the harbour and it became rare around Ripapa Island.

(16) *Sigapatella novaezelandiae* (Fig. 15.16)

Sigapatella is a gasteropod, very similar to *Zegelerus tenuis* in its mode of life. Both are normally found attached to shells or rocks but *Sigapatella* appeared to have a smaller overall range, being limited to the area around the eastern tip of Quail Island. As with *Zegelerus*,eggs are brooded in the mantle cavity. *Sigapatella* is unusual in that it is a filter feeder and does not need to move to feed.

(17) *Xymene plebejus* (Fig 15.17)

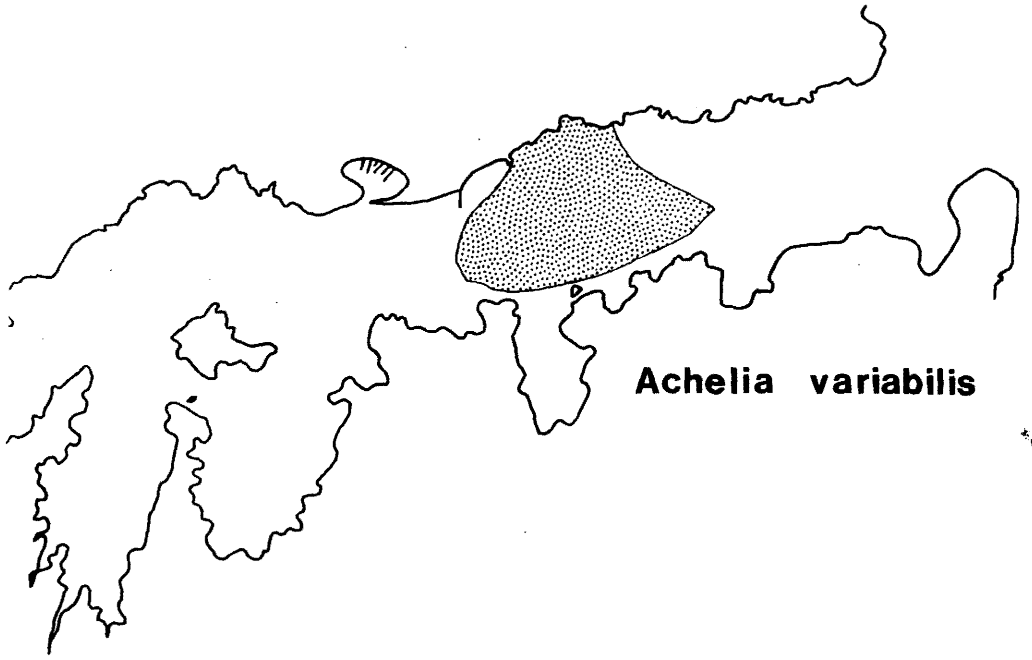
Xymene is a small whelk, ubiquitous in the upper harbour with the exception of the wave affected areas near the low water mark in Governors Bay, Head of the Bay, Charteris and Purau Bays. Densities were highest in the area between the northern coast of Quail Island and off the mouth of Purau, near Ripapa Island. *Xymene* is carnivorous and it appeared from examination of samples containing it that it fed on juveniles of *Chione*, *Maoriomactra*, and *Spisula*. The valves of these were penetrated by a small circular hole with a diameter of 0.75 millimetres that corresponded to the expected size if *Xymene* was the predator.

FIG 15.15

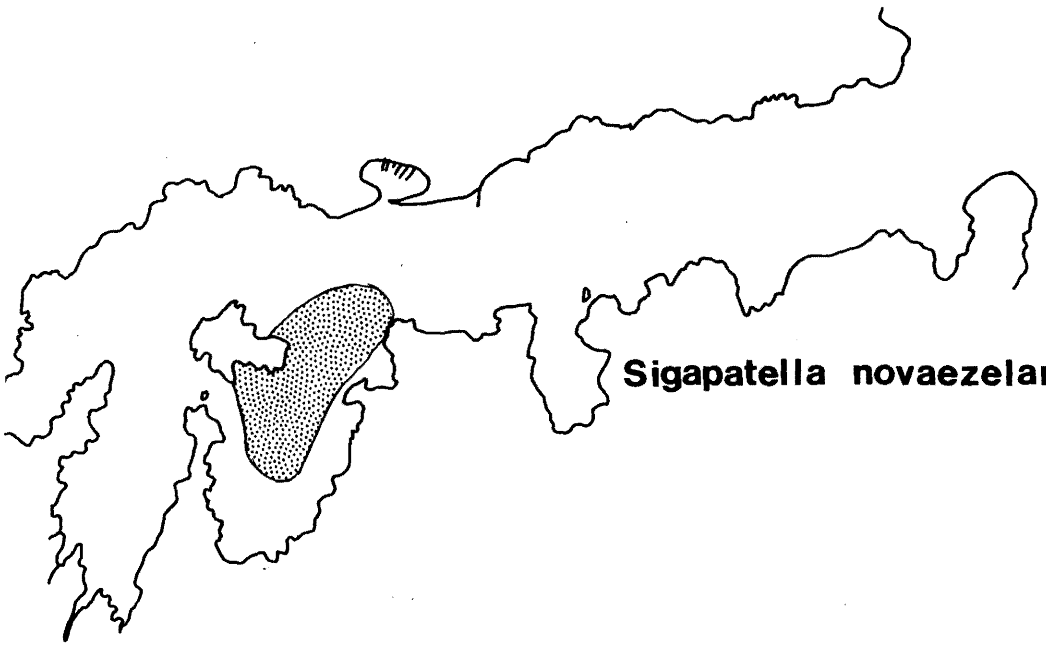
The distribution of *Achelia variabilis* in Lyttelton Harbour.

FIG 15.16

The distribution of *Sigapatella novaezelandiae* in Lyttelton Harbour



Achelia variabilis



Sigapatella novaezelandiae

(18) Hemiplax hirtipes (Fig 15.18)

This small mud crab was the major inhabitant of the muddy upper harbour. It became particularly dense along the stretch of bottom between Governors Bay and the wharves area. Hemiplax was absent from the sandy portion off Purau mouth but was present in Purau Bay. Normally it lives in a tunnel dug in the muddy bottom which must be of such a consistency that it will not crumble in. At the low tide marks the position of Hemiplax is occupied by a very similar crab Helice crassa, (Stephenson 1970). Hemiplax is a scavanger and detrital feeder sifting through the mud for food particles. Hemiplax is the main food of the puffer Uranostoma richei Habib (1971) and contributes to the diet of many other harbour fish, (personal observations).

(19) Trochus tiaratus (Fig 15.19)

Trochus is a herbivorous gasteropod feeding by rasping algal growths off rock and shell surfaces. It is widespread over the sandy portions of the harbour with local concentrations near Ripapa Island and the eastern tip of Quail Island. Elsewhere sampling showed that the average densities were higher in the area off Diamond Harbour, declining northward across the harbour (see Fig. 15.19).

The lack of rocks and other objects for algal attachment may be limiting the spread of Trochus into the muddy regions.

(20) Asterina regularis (Fig 15.20)

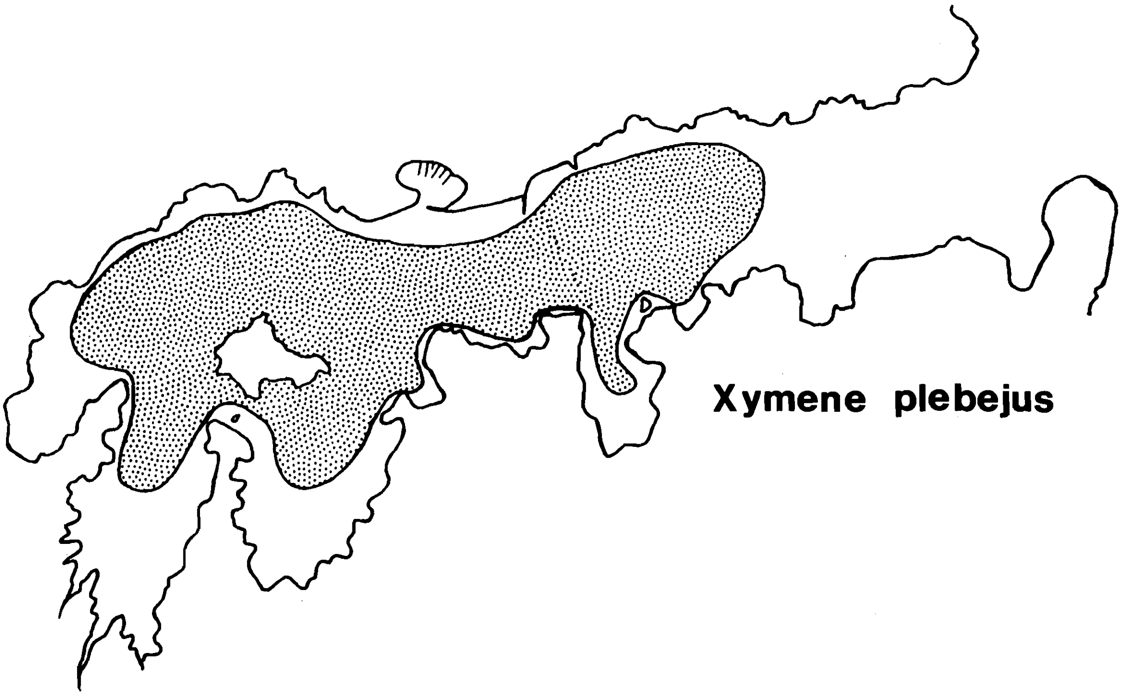
This asteroid was present in almost all samples but reached a maximum density north of Quail Island. The occurrence became scattered in the sandy regions.

FIG 15.17

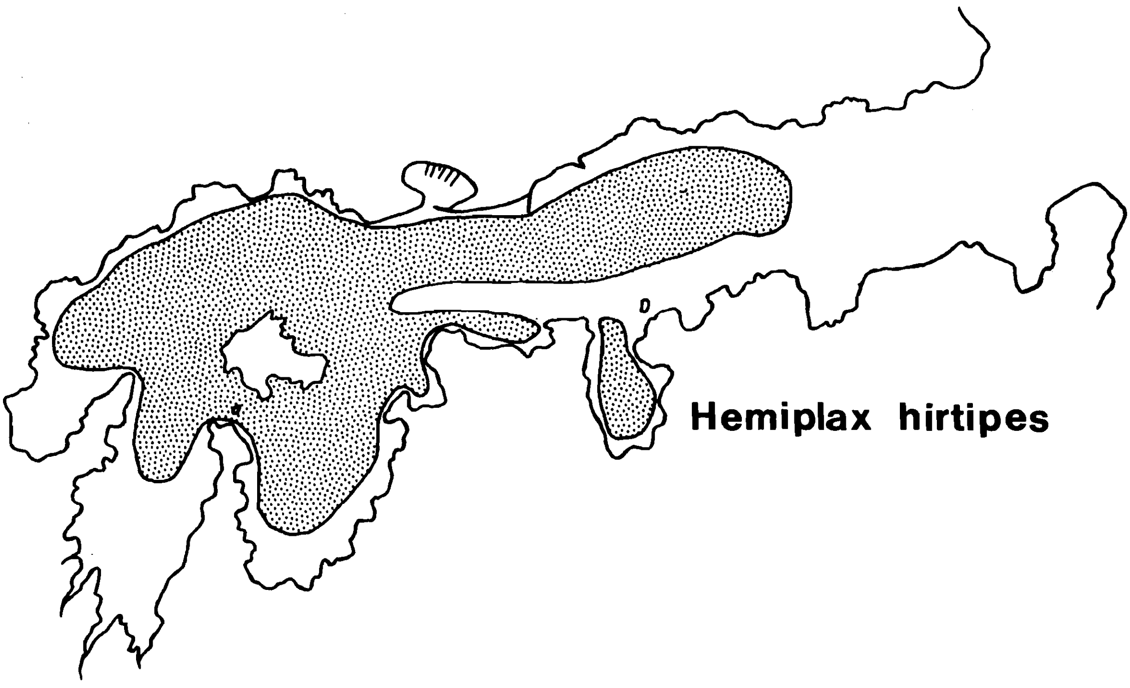
The distribution of *Xymene plebejus* in Lyttelton Harbour.

FIG 15.18

The distribution of *Hemiplax hirtipes* in Lyttelton Harbour.



Xymene plebejus



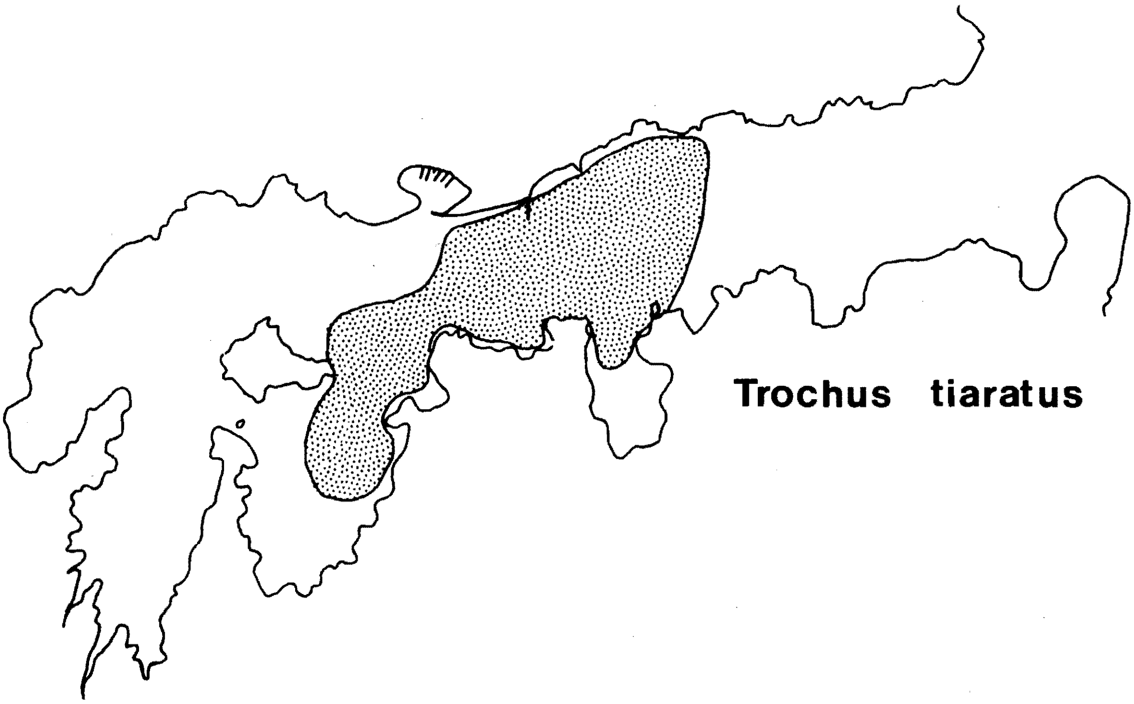
Hemiplax hirtipes

FIG 15.19

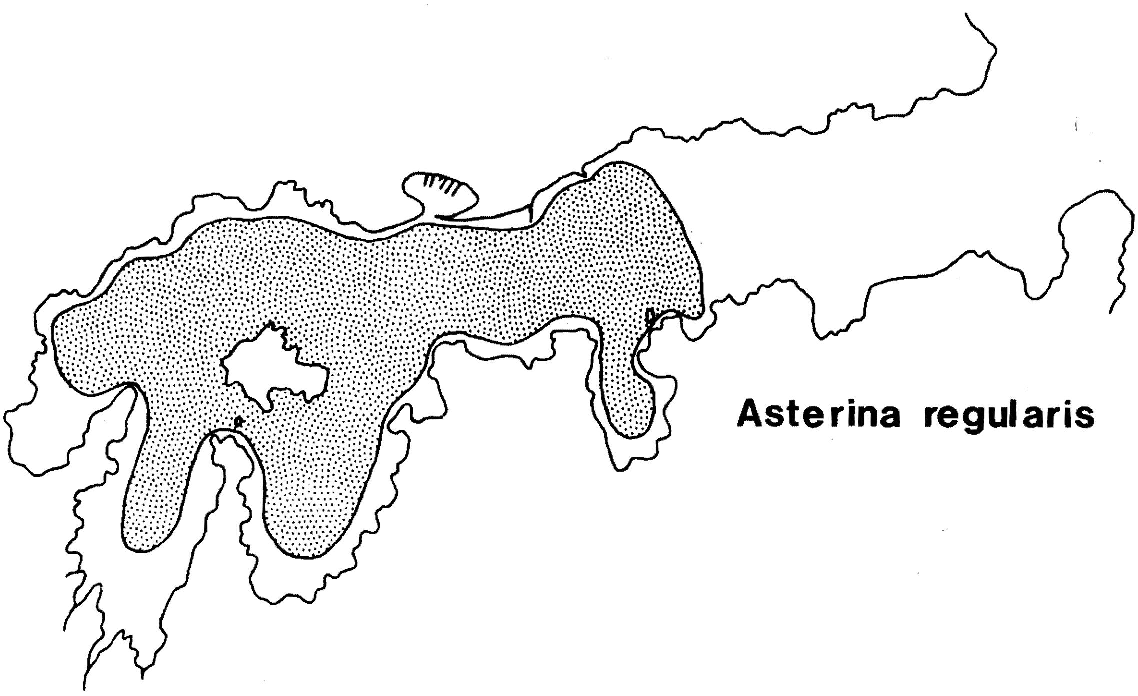
The distribution of _Trochus tiaratus_ in Lyttelton Harbour.

FIG 15.20

The distribution of _Asterina regularis_ in Lyttelton Harbour.



Trochus tiaratus



Asterina regularis

Asterina extended almost to the low tide mark in Governors Bay and Charteris Bay, and well into Purau Bay. It appeared to be little affected by the presence of algae in the upper harbour, numbers staying constant after the growth appeared.

There is a marked seasonal movement with the numbers is shallow parts of the harbour decreasing greatly during the winter months and migrating back in the spring. What these animals were eating was not able to be determined. Stomachs opened contained only debris and it is possible that these are detrital feeders and scavengers.

(21) *Nucula hartvigiana* (Fig 15.21)

Only a small area to the south east of Quail Island is inhabited by *Nucula*, a small bivalve, but here they were present in densities of up to ten per square metre. Many empty shells had been bored by *Xymene plebejus*.

Nucula did not penetrate into the muddy portions of Charteris Bay and generally remained in the deeper parts of the bay where the incoming tidal current was effective.

(22) *Maoriomactra ordinaria* (Fig 15.22)

This bivalve species occurs in Lyttelton Harbour along with a very similar but larger species *Spisula aequilateralis*. The distribution follows fairly closely the bounds of the sandy regions opposite Purau and Charteris Bays.

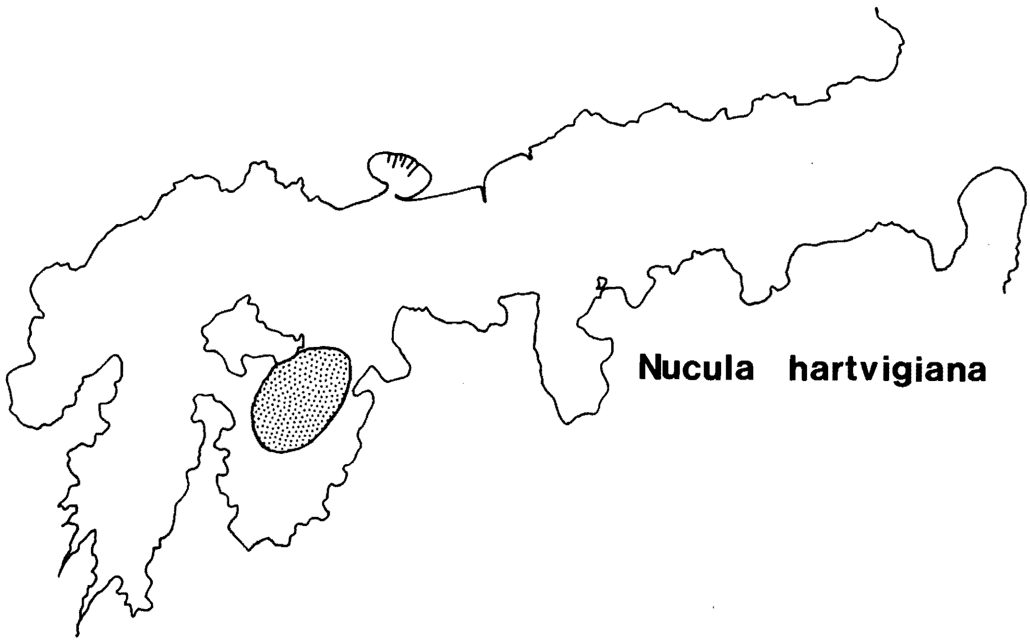
In January/February 1970 there was a very heavy spatfall of *Maoriomactra* and off Quail Island densities of over 100 per square metre were recorded. This later declined, presumably by predation or competition,

FIG 15.21

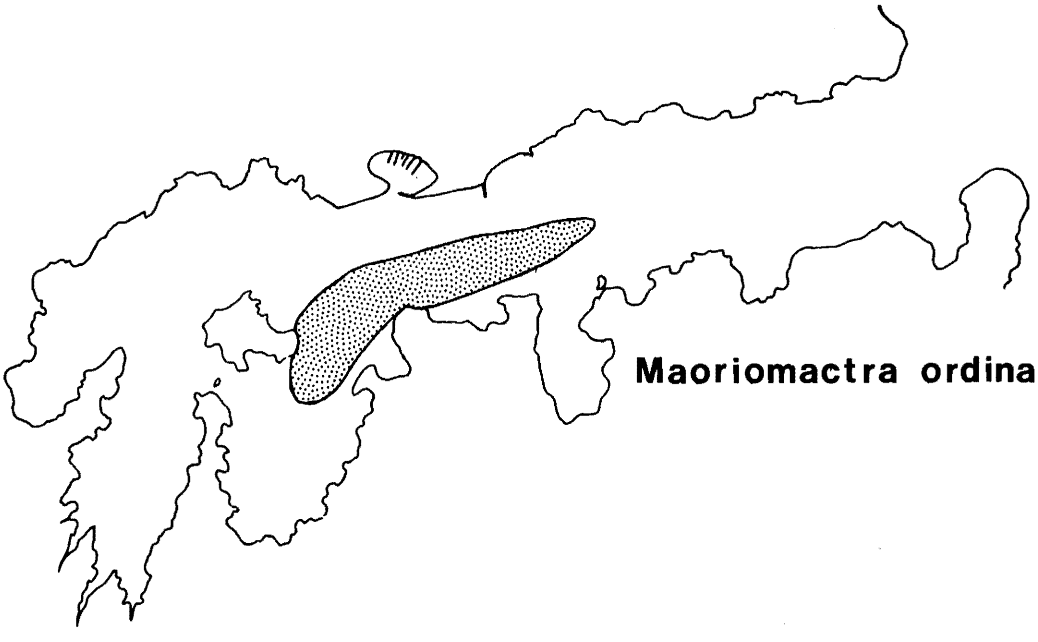
The distribution of *Nucula hartvigiana* in Lyttelton Harbour.

FIG 15.22

The distribution of *Maoriomactra ordinaria* in Lyttelton Harbour.



Nucula hartvigiana



Maoriomactra ordinaria

to the more normal figure of 3 to 4 per square metre. There was found to be a local concentration around a partly exposed reef midway between the eastern tip of Quail Island and the mooring basin. Again examination of empty valves showed that Maoriomactra was a target for shell boring whelks. Over the sampling period of 13 months the populations of Maoriomactra appeared to fluctuate without any readily apparent pattern.

(23) Ostrea heffordi (Fig 15.23)

The oyster beds of Lyttelton Harbour have been heavily exploited by local inhabitants for many years, and because of this are certainly not in a natural state. In all samples taken there was a vast preponderance of juvenile Ostrea. This may imply that the population has been over fished. Ostrea requires a firm base to which the lower valve can be cemented. This type of attachment surface is quite rare in the harbour. Of the many objects that were accidently caught during dredging, including lengths of pipe, a rubbish can, numerous bottles, and an old broom, most had some juvenile Ostrea attached. The distribution indicates that attachment surfaces are the limiting factor for Ostrea populations. The map showing occurrence was compiled on the basis of sites sampled that had objects with Ostrea attached. There appeared to be no reason why Ostrea could not be more widespread given suitable substrates.

(24) Nectocarcinus antarcticus (Fig 15.24)

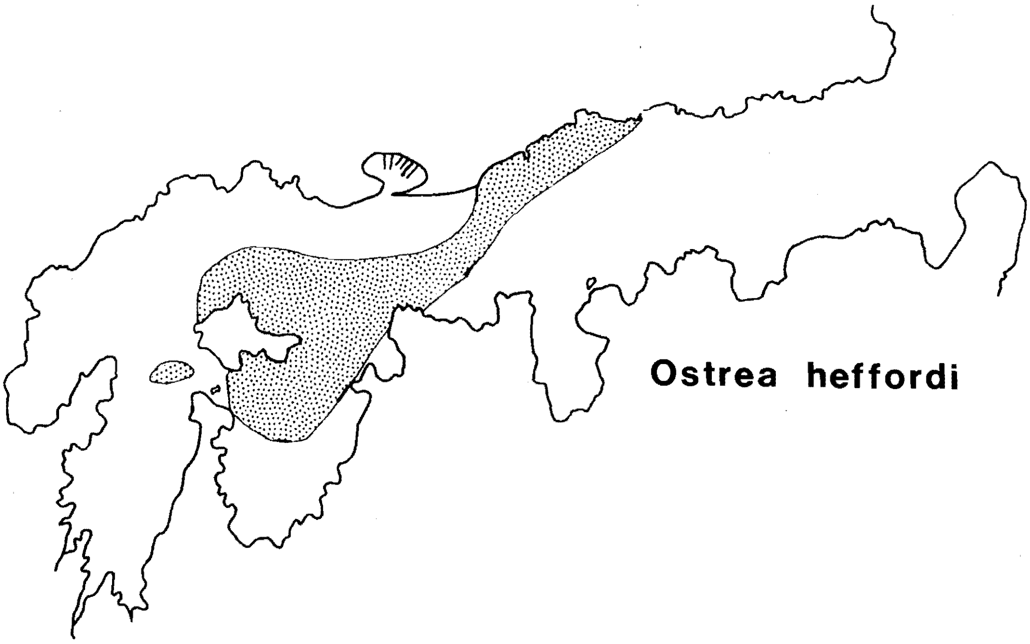
This species is a large, aggressive, swimming crab and shares its range with a similar form, Ovalipes bipustulatus. The map shows the rather unusual

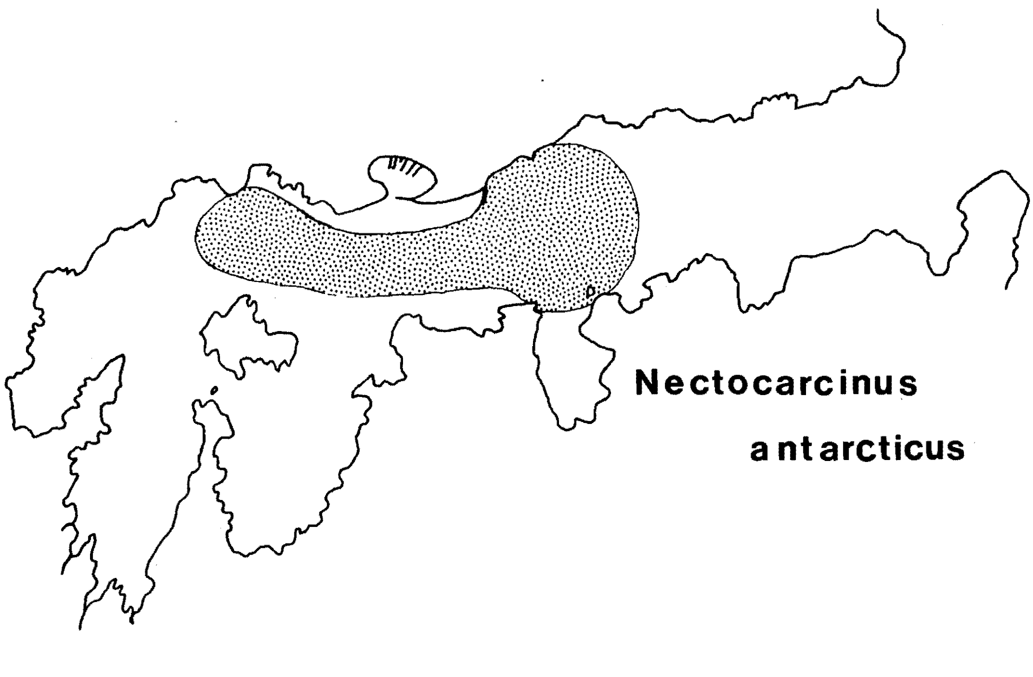
FIG 15.23

The distribution of Ostrea heffordi in Lyttelton Harbour.

FIG 15.24

The distribution of Nectocarcinus antarcticus in Lyttelton Harbour.


Ostrea heffordi


Nectocarcinus
antarcticus

distribution, avoiding the very sandy areas and having its maximum density to the north of Quail Island. Nectocarcinus is a predatory and scavanging carnivore. There was a migration from the upper harbour areas during the winter months with a corresponding increase in numbers off Purau Bay. Local concentrations were evident near reefs.

3.8 The benthic fauna as fish food

The most common fish in the sampling area over the investigation period were the puffer fish, Uranostoma richei; the sole, Peltorhamphus novaezealandiae; red cod, Physiculus bachus; the gurnard, Lepidotrigle brachyoptera; spotted stargazer, Geniagnus monopterygius the trevally, Caranax lutescens; and flounder Rhombosolea plebia.

Most of these, with the exception of the puffer, sole, and flounder, were juveniles and their food preferences generally reflected their small size and relatively undeveloped jaws. Many stomachs contained Mysis sp. and the small isopods and amphipods found in the upper harbour, particularly where algal growth was abundant.

Uranostoma has been shown by Habib (1971) to feed almost exclusively on the crab Hemiplax hirtipes. The puffer has very strong jaws with the teeth forming a "beak" as in the parrot fishes. The very strong construction allows it to crush Chione shells and crab carapaces with little effort. Also prominent in the diet of the puffer, and of most other harbour fishes when it is available, is the shrimp Pontophilus australis. Opened guts of Uranostoma, Physiculus, and Caranax have been found packed with Pontophilus.

A favourite food item with the gurnard is the small cuttle fish Sepioloidea pacifica. Sepioloidea also figures in the food of most other predatory species. Geniagnus, the star gazer, seems to feed mainly on other fish, for which it lies in wait partly buried in the mud with only its eyes showing. But Hemiplax and other crab species also occur in its food.

Generally speaking the amount and type of food of most fish varies over the year as the abundance of certain elements of the benthic fauna changes. The crustacea are prime targets with the shrimps and small crabs receiving most attention. Juvenile fish are much more abundant in the harbour, since in many cases it acts as a nursery area, than in Canterbury Bight and other off shore areas.

Most of this information was gained from specimens caught while trawling in Lyttelton Harbour using an otter trawl. Detailed information on the puffer was by courtesy of G. Habib.

As has been mentioned earlier in this section, there was a mystery about the disappearance of juvenile Chione and Myadora from areas outside the established beds. Many fishes had fragments of shell that was tentatively identified as Chione. It is possible that the juvenile Chione and Myadora, having very thin almost transparent shells, are a food source for benthic feeding fishes. This may not be the full answer since the numbers recovered did not seem to correspond to the numbers that would need to be consumed to account for each year's spat fall.

3.9 Conclusions

The bulk of the fauna is restricted to the sandy mud portions of the harbour. These principally are in a strip extending from Ripapa Island to Quail Island.

The nature of this substrate seems to have been determined and maintained by the tidal currents as described in section two.

While the highest proportion of organic material is found in the muds there is still a sufficient quantity in the sandy muds to support the many detrital feeders there.

The largest beds of filter feeding lamellibranchs are also located along the current tracks. This is shown particularly well by consideration of the distribution diagrams of <u>Chione stutchburyi</u> and <u>Myadora striata</u>.

With the type of sediment divided into the three classes; sandy, sandy mud, and muddy, there is clearly a change in the relative proportions of the three types of animals; filter feeders, detrital feeders, and predators. Detrital feeders predominated in the muddy regions, filter feeders in the sandy mud parts, and there was a slightly higher proportion of filter feeders in the sandy regions.

While the 24 indicator species were chosen for their abundance and ability to show certain tendencies, the species list shows that there were many other species found although many were very rare. Most of the fauna corresponds to that common throughout New Zealand in a sheltered shallow water inlet such as Lyttelton. Similar associations were found by Powell (1937) in Auckland and Manukau Harbours.

SECTION 4

COMMUNITIES

4.1 Introduction

Assemblages of animals are very rarely present as discrete groups with clear cut boundaries. Grouping therefore must be inferred from consideration of the interaction of the fauna with various physical and chemical factors. The habitat must be shown to be reasonably constant, supporting a stable population before the existence of a community is considered. In most regions one or more species seem to dominate samples, and providing they are a permanent feature of the local fauna, may be termed indicator species. Such species usually have varying tolerances within the study zone and may serve to delimit communities. This approach may not be valid where a rarer animal shows a very patchy distribution at points where its narrow requirements are met exactly.

4.2 Community concepts

The pioneer in benthic community ecology was undoubtedly Petersen whose major publications (Petersen, 1913 and 1914), set up basic principles which have been used by most later investigators as a starting point for their own approaches. Since that time the recognition of communities have become a basic aim of benthic ecological studies. Two schools of thought have evolved, the statistical and biological approaches. Petersen was an adherent of the former with the aim of avoiding subjective conclusions. Conclusions reached by his followers may have reflected the interests and training of the investigators rather than the true structure of the communities. Fager (1963) adapted the approaches of terrestrial botanists, and in particular the French worker, Braun Blanquet, in developing an equation that would analyse "recurrent groups" directly. This dispensed with the need to assign species positions of dominance, sub-dominance, and associate before approaching the problem of defining "natural" groups.

Thorson (1957), in reviewing the benthic communities of continental shelf regions followed the Petersen school of thought but did not resort to a purely statistical description. He had in the course of his investigations recognized similar assemblages in widely separated areas. These soft-bottomed shelf communities varied in their complement of species, but generally it was shown that there were similar habitats occupied by different species of the same groups in each area. These were termed parallel communities by Thorson.

This distinction of communities may be valid where they are geographically separated but the transition between one community and the next may be very indistinct. Elton (1927) discussed the merging of adjacent communities and criticized the extreme elasticity in the definition of communities with regard to size and content. Very few communities are completely homogeneous, there almost always being changes in the ratios of species present away from the "centre" of the community. Centre in this context is a nebulous word since this can only be an arbitrary point used to define the community type.

The individual investigator must have clear in his own mind the degree to which he will tolerate heterogeneity in assemblages that he regards as communities. The extremes of splitting are usually found among workers describing diverse, rocky substrates where the living spaces available increase greatly but may also be found in descriptions of level, soft-bottomed areas. "There can be no rules from which to define limits in this respect and the outcome is very much a matter of tact, sociological training and experience" (Braun Blanquet, 1964).

The next logical step from this somewhat confused situation is to consider the possibility of a continuum. It has been defined as that state where the fauna changes continuously and is not differentiated, except arbitrarily, into sociological entities (McIntosh, 1958). Brown and Curtis (1952) described it as a gradient of communities, in which species were distributed in a continuously shifting series of combinations, in a definite sequence or pattern. Therefore the continuum is a construction based on studies within a specified faunistic region. It is not an assorted mass of animals, with no plan or cohesion.

Marine biologists traditionally have recognised discrete communities of benthic and littoral organisms, but the continuum aspect is supported by many recognised workers in the field, (Tischler, 1950: Sanders, 1960: Wieser, 1960: Kilburn, 1961: Margalef, 1962: and Udvardy, 1964). Sanders (1960) in discussing the sediments of Buzzards Bay, suggested a continuum changing with the variation in sediment quality.

A problem that is common to all of these situations is the subjective conclusion, that although adequate when describing obvious cases of dominance, does not hold up so well when a group of animals, although closely integrated, has no indicator species. These are not immediately obvious, and often are proven only when the statistical approach taken. The statistical analysis of community species composition has tended to lag, probably because of the complexities of some systems, and a possible general distrust of figures where intuition does not agree.

In the consideration of possible communities in Lyttelton Harbour the statistical approach, which has been proven in these circumstances by Cassie and Michael (1968), Fager (1968), Kelly (1970), Stephenson et al (1971), has been used. The only serious source of subjective error may be in sampling. To minimize this the sample sites were randomly spread over the different types of substrate mainly with the intention of establishing their limits. There was no plan to intensively sample certain areas of these.

4.3 Stability of the region

A well established community must be based on a stable substrate since any change in depth, or alteration in grade of substrate may upset the ecological balance. A comparison of the depths along three transects is shown in Figs. 4 and 5. The first of these was taken from a map prepared from sounding taken by the H.M.S. Acheron in 1849, and the other from present day data.

Changes have been very small, considering the extensive dredging, with a slight tendency towards deepening being evident. Considering the apparent constancy of depth over the past 120 years the area may be considered stable.

4.4 Fager's recurrent groups analysis

This is the first of two approaches taken to define communities (Fager 1957). This is based on a t-test expression evolved by Cole (1949)

$$t = \frac{(n_A + n_B)(2J-1)}{2 n_A n_B} - 1 \qquad n_A + n_B - 1$$

This equation measured changes in the relative frequency of occurrence of two species. It is assumed that the probability of finding species A is n_A/n_A+n_B and that of finding species B is n_B/n_A+n_B, where n_A and n_B are the number of occurrences of species A and B respectively. Making the probabilities of finding the two species relative to the sum of their occurrences improves the chances of finding an association between two species that occur in most samples, and removes the premium or rarity.

Where n_A is less than n_B the number of joint occurrences, designated J, assuming independent distribution will have a hypergeometric distribution with the expected J equal to $n_A n_B/n_A + n_B$ and the variance from the expected expressed by $(n_A n_B)^2/(n_A+n_B)^2$ $(n_A + n_B - 1)$.

Subsequently it was found that this expression did not follow the hypergeometric distribution accurately (Fager and McGowan, 1963), and it was replaced by the basically similar expression:

$$I = J/ \quad n_A n_B \quad - \tfrac{1}{2} \quad n_B \quad \tfrac{1}{2} \quad n_B$$

where I represents an "index of affinity". This gives the geometric mean of the proportion of joint occurrences. It was considered that to be significantly associated species should have joint occurrences at at least one third of the sites concerned. A value of I equal to or greater than 0.33 indicated significant affinity.

The 24 most abundant animals, the indicator species, were used in this analysis and the results indicated on a trellis diagram as detailed in Fager (1957). This is shown in Fig 16, where a significant affinity is designated as "+" and an insignificant affinity as "-".

Following the instructions and text given in Fager (1957, pp. 589-591), groupings were extracted and tabulated diagramatically in Fig 17.

4.4.1 Results

Analysis of the matrix produced three major groups. These are expressed diagramatically in Fig 17.

Pontophilus australis, *Hemiplax hirtipes*, *Virgularia gracillima*, *Xymene plebejus*, and *Micrelenchus huttoni* composed the first of these. They represented the typical fauna of the muddy regions of the upper harbour, particularly the regions to the north of Quail Island.

The second group comprised *Zeacolpus vittatus*, *Pectinaria antipoda*, *Trochus tiaratus*, and *Myadora striata*. These are members of the coarser sand areas of the harbour.

The third recognised assemblage included two sessile molluscs that require a firm base for successful attachment. These are the oyster, *Ostrea heffordi*, and the unusually modified gasteropod, *Sigapatella novaezelandiae*. Also present was the small spider crab, *Halicarcinus whitei* which may be classed as a "shelterer" found wherever there are broken shells to which the abovementioned molluscs attach.

The first two groups were composed of the animals that could live in extremes of sediment grades although

FIGURE 16

A trellis diagram drawn from the results of Fager's Recurrent group analysis. "+" indicates significant affinity "-" indicates insignificant affinity. This is a species/species matrix.

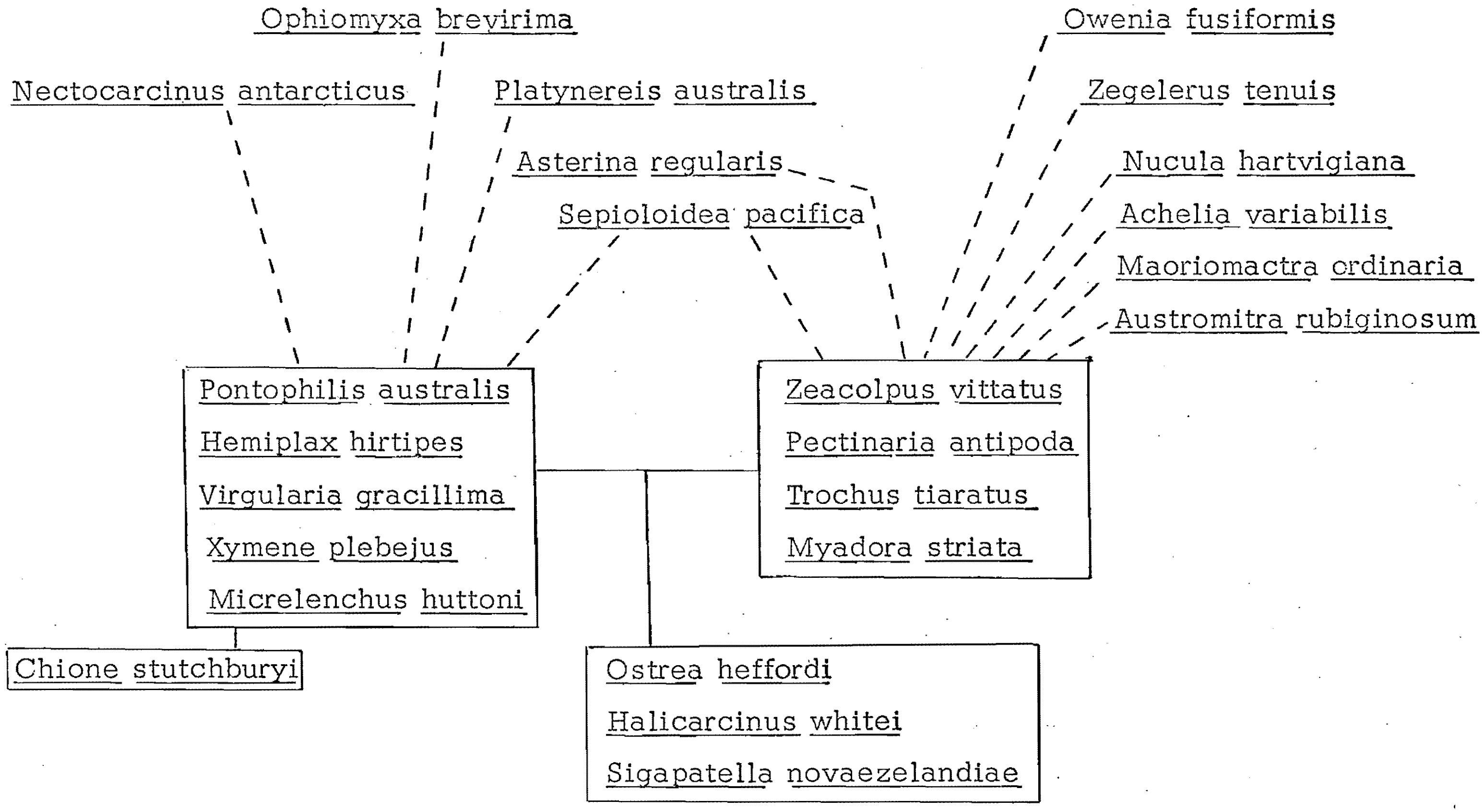
SPECIES																									TOTAL
1	0	+	−	+	+	−	−	−	−	+	−	+	−	−	−	−	−	−	−	−	+	−	−	−	6
2	+	0	−	−	+	−	−	−	−	+	−	+	−	−	−	−	−	−	−	−	+	−	+	−	6
3	−	−	0	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	1
4	+	−	+	0	−	−	+	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	4
5	+	+	−	−	0	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	2
6	−	−	−	−	−	0	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0
7	−	−	−	+	−	−	0	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	2
8	−	−	−	−	−	−	−	0	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	1
9	−	−	−	−	−	−	−	−	0	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0
10	+	+	−	−	−	−	−	−	−	0	−	+	−	−	−	−	−	−	−	−	+	−	−	−	4
11	−	−	−	−	−	−	−	−	−	−	0	−	+	+	−	−	−	−	−	−	+	−	−	−	3
12	+	+	−	−	−	−	−	−	−	+	−	0	+	−	−	−	−	+	−	−	−	−	+	−	6
13	−	−	−	+	−	−	+	−	−	−	+	+	0	+	−	−	−	−	−	−	−	−	−	−	5
14	−	−	−	−	−	−	−	−	−	−	+	−	+	0	−	−	−	−	−	−	+	−	−	−	3
15	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0	−	−	−	−	−	−	−	−	−	0
16	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	0	−	−	−	−	−	−	−	−	1
17	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	0	+	−	−	−	−	−	−	2
18	−	−	−	−	−	−	−	+	−	−	−	+	−	−	−	−	+	0	−	−	+	−	−	−	4
19	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0	−	+	−	+	−	2
20	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0	−	−	−	−	0
21	+	+	−	−	−	−	−	−	−	+	+	−	−	+	−	−	−	+	+	−	0	−	−	−	7
22	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0	−	−	0
23	−	+	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−	−	−	0	−	3
24	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	0	0

SPECIES KEY

1 = Hemiplax hirtipes
2 = Virgularia gracillima
3 = Trochus tiaratus
4 = Zeacolpus vittatus
5 = Owenia fusiformis
6 = Platynereis australis
7 = Austromitra rubiginosa
8 = Zegelerus tenuis
9 = Chione stutchburyi
10 = Asterina regularis
11 = Ostrea heffordi
12 = Xymene plebejus
13 = Micrelenchus huttoni
14 = Halicarcinus whitei
15 = Ophiomyxa brevirima
16 = Sigapatella novaezelandiae
17 = Myodora striata
18 = Pectinaria antipoda
19 = Sepioloidea pacifica
20 = Maoriomactra ordinaria
21 = Pontophilis australis
22 = Nectocarcinus antarcticus
23 = Achelia variabilis
24 = Nucula hartvigiana

FIGURE 17

A schematic representation of the communities and proposed continuum derived from Fager's recurrent groups analysis



Ophiomyxa brevirima
Nectocarcinus antarcticus
Platynereis australis
Asterina regularis
Sepioloidea pacifica
Owenia fusiformis
Zegelerus tenuis
Nucula hartvigiana
Achelia variabilis
Maoriomactra ordinaria
Austromitra rubiginosum
Pontophilis australis
Hemiplax hirtipes
Virgularia gracillima
Xymene plebejus
Micrelenchus huttoni
Zeacolpus vittatus
Pectinaria antipoda
Trochus tiaratus
Myadora striata
Chione stutchburyi
Ostrea heffordi
Halicarcinus whitei
Sigapatella novaezelandiae

their ranges were not entirely confined to these many having a vastly greater range, (see Figs 15.1 to 15.24). The third group did not appear to be very restricted to any particular region but, providing attachment and shelter were present, could live in most places.

After removal of these twelve species twelve remained that did not show any particularly strong affinities. At this stage field experience may be used in an attempt to classify these into some type of grouping. The species that stands out in this respect is Chione stutchburyi. This exists in almost pure and very dense beds. These are to the north of Quail Island and there is a very sharp division between the beds and the adjacent muddy regions. With these facts in mind Chione may be placed in a group of its own and accorded community status.

The remaining eleven species exist in varying concentrations over the area of bottom that have been designated sandy mud. Fig 8 shows these species placed above the main groupings and joined to these by dashed lines. The implication here is that there is a continuum of species in the sandy mud region with a gradation of species densities from the preferred type of substrate towards the extremes. Most of the inhabitants show some preference for a more muddy or more sandy type and the dashed lines indicate the leanings of the various inhabitants.

Some difficulties enter when the mobility of the inhabitants is considered. Animals such as Nectocarcinus antarcticus and Sepioloidea pacifica are good swimmers and may travel large distances. Capture of these under such circumstances may be pure chance.

All of the species used as indicator species have proved to be present on all sampling dates.

4.5 Multiple discriminant analysis

The second approach, multiple discriminant analysis, is a form of multivariate analysis designed to work with a large number of variables and form groupings of sites showing affinity with one another. In the present study the same 40 sites which were considered in section 2, sediments, were used. The numbers of each of the 24 indicator species present at each site, along with the percentage of each of the seven sediment size classes, and the percentage of organic carbon were punched out onto computer cards. The organic carbon value and sediment parameters used here were as displayed on the histograms in section 2. This carbon value is not the same as organic material (see appendix 2).

The discriminant analysis program was taken from the I.B.M. System 360 Scientific Subroutine Package Programmers Guide (360A-CM-03X). Known as MDISC the program was run on an I.B.M. 360/44 computer.

The present study was undertaken to determine if the measurements that had been taken were useful and whether discriminant function analysis might be a worthwhile statistical method for making classificatory decisions about individual sites. To do this it had to give satisfaction in two directions.

The first of these necessitated that the result obtained bear some resemblence to those obtained from Fager's recurrent species analysis. Although the discriminant function analysis was dealing with sites rather than individual species' distributions, Fager's analysis had shown that there were two fairly well defined muddy and sandy communities.

Secondly it had to show some relationship to the picture built up over the sampling period of the inhabitants and their affinities. One should regard with skepticism a statistical method which yields results that differ from the observed biological situation.

Initially it was decided that there may be 4 groups distinguishable on the basis of sediment type. The 40 sites were then grouped into four groups of ten sites. These decisions were made on the sediment type alone but the discriminant analysis program would take into account the numbers of species and the organic carbon content at each site as well.

The sites in the four groups, after being subjected to this initial discriminant function analysis, were re-assigned. Instead of being four groups of ten the number in each group were 4, 5, 24 and 7 respectively (see table 2). The first of these groups, h21, h20, n12, g28, presented a puzzle since there seemed to be no binding factor. The only possibility was that this was brought about by an abundance of the shrimp <u>Pontophilus</u> <u>australis</u> at these sites. This hypothesis was arrived at by examining the raw data sheets.

The second group, j15, j10, j9, k8, i20, comprised mostly the <u>Chione</u> <u>stutchburyi</u> bed. The last of the group i20, although not in the main bed correspond to an isolated occurrence of <u>Chione</u> in the middle harbour (see Fig 15).

The third group, g22, g20, h20, l12, m12, k12 k14, g14, g22, h6, i4, g9, h11, j5, h10, j24, i24, h18, g23, f23, i7, m15, i13, h8, covered all of the sandy

TABLE 2

Evaluation of classification functions for each observation.

Observation	Probability associated with largest discriminant function	Largest function No	Site No
Group 1			
1	1.00000	1	h21
2	1.00000	1	h20
3	1.00000	1	n12
4	1.00000	1	g28
Group 2			
1	1.00000	2	j15
2	1.00000	2	j10
3	1.00000	2	j9
4	1.00000	2	k8
5	1.00000	2	i20
Group 3			
1	1.00000	3	g22
2	1.00000	3	g20
3	1.00000	3	h20
4	1.00000	3	l12
5	1.00000	3	m12
6	1.00000	3	k12
7	1.00000	3	k14
8	1.00000	3	g14
9	1.00000	3	g22
10	1.00000	3	h6
11	1.00000	3	i4
12	1.00000	3	g9
13	1.00000	3	h11
14	0.98277	3	j5
15	1.00000	3	h10
16	1.00000	3	j24
17	1.00000	3	i24
18	1.00000	3	h18
19	1.00000	3	g23
20	1.00000	3	f23
21	1.00000	3	i7
22	1.00000	3	m15
23	1.00000	3	i13
24	1.00000	3	h8
Group 4			
1	1.00000	4	i23
2	1.00000	4	i25
3	1.00000	4	j21
4	1.00000	4	i22
5	0.99999	4	i22
6	1.00000	4	j19
7	0.99951	4	i19

mud and muddy regions and basically may be considered to include the continuum that was suggested by the results of Fager's recurrent groups analysis.

The fourth group, i23, i25, j21, i22, j19, and i19, falls into the sandy region in the vicinity of Purau Bay mouth.

The generalized Mahalanobis D-square was 23525.7. Dixon (1964) states that this value may be used as chi-square under assumption of normality with m(g-1) degrees of freedom. In this content m represents the number of variables and g the number of groups formed from the variables. In the present study the chi-square value with 120 degrees of freedom is very highly significant. This may be interpreted as indicating that there is very little probability that the groups as indicated could have been formed by chance and that the separation between them is complete and very large.

Discriminant analysis was used to formulate 4 groups. When each of the discriminant equations, (see Table 3), evolved in the computation was applied to coefficients derived by consideration of all of the available parameters at each site a set of discriminant values was produced. There are four sets of discriminant values, that is, four values for each site.

The separation of the groups may be checked visually by graphing the discriminant values as functions against one another. Fig 18. shows the separation achieved by graphing functions 1 and 2 and Fig 19 shows the result of the graphing of functions 3 and 4. At first glance three groups stand out as clearly differentiated with the fourth rather indistinctly separated. Considering both graphs there is clearly a

Discriminant equation 1

Constant	Coefficients						
-3028.15015	-4.40996	2.71283	56.44562	23.94910	0.95153	-130.14763	166.43361
	-105.03888	12.04775	15.15797	26.04813	18.29549	-0.37573	72.13173
	-10.90813	35.88974	0.99983	59.53621	286.15674	11.54417	3.47669
	-79.80913	-96.71338	119.19556	133.64615	0.61783	0.52703	1.02462
	-0.11926	0.17533	0.01454	0.21358	0.26378		

Discriminant Equation 2

Constant	Coefficients						
-3805.32788	-5.37441	5.85662	59.75351	-20.76714	2.89088	-0.86669	-188.47400
	48.11588	27.79413	-267.64893	106.05042	7.78630	0.65109	-22.81070
	0.25606	-78.10808	3.33713	30.24744	785.72144	14.26652	1.88739
	-53.77240	-52.80365	59.29210	476.11475	-0.11612	0.29469	1.50460
	0.25647	0.19062	-0.10973	0.32015	0.38260		

Discriminant Equation 3

Constant	Coefficients						
-949.52881	-3.15696	0.36437	27.70026	-6.34986	0.92765	-45.88184	15.24657
	-27.84807	6.89169	-68.81090	29.02971	12.58476	-0.83399	13.35067
	1.23488	-5.73029	-1.57585	17.05878	133.75278	5.04321	0.78711
	-45.08394	-58.73134	33.90375	102.18906	0.14906	0.30258	0.53468
	0.15433	0.17222	0.02621	0.17623	0.21428		

Discriminant Equation 4

Constant	Coefficients						
-1081.87500	-3.68167	-0.08899	28.32721	-6.59408	0.73887	-58.87679	36.34485
	-37.33089	6.78447	-61.41321	22.37012	14.57577	-1.06506	18.12729
	3.33852	-0.96921	-2.64753	18.87604	142.82465	4.74458	0.89168
	-45.39168	-66.79053	37.86493	95.39740	0.19594	0.34092	0.56534
	0.14011	0.19405	0.03760	0.18326	0.22366		

TABLE 3 DISCRIMINANT EQUATIONS

difference in the discriminating powers of the different functions. In Fig 18 function 1 is more efficient in separating the fourth group from the mass of sites representing the sandy and sandy mud regions, while function 2 is more efficient in discriminating the Chione bed and the sand group. Group 4 is represented as squares in the diagram purely to aid in distinguishing it from the mass of group 3. Group 3 represents the sandy mud regions, the site of the continuum suggested by the results of Fager's analysis in section 4.4.

One member of group 4 is displaced from the bulk of the group and apparently associated with group 3. This site, i19, may be seen by consulting table 2 to have a rather lower probability that it is associated with that group than the rest. No obvious explanation for this is apparent but it is possible that site i19, being on the border of the dredged area is modified to a very great extent and has lost the affinity that it had with the surrounding sites.

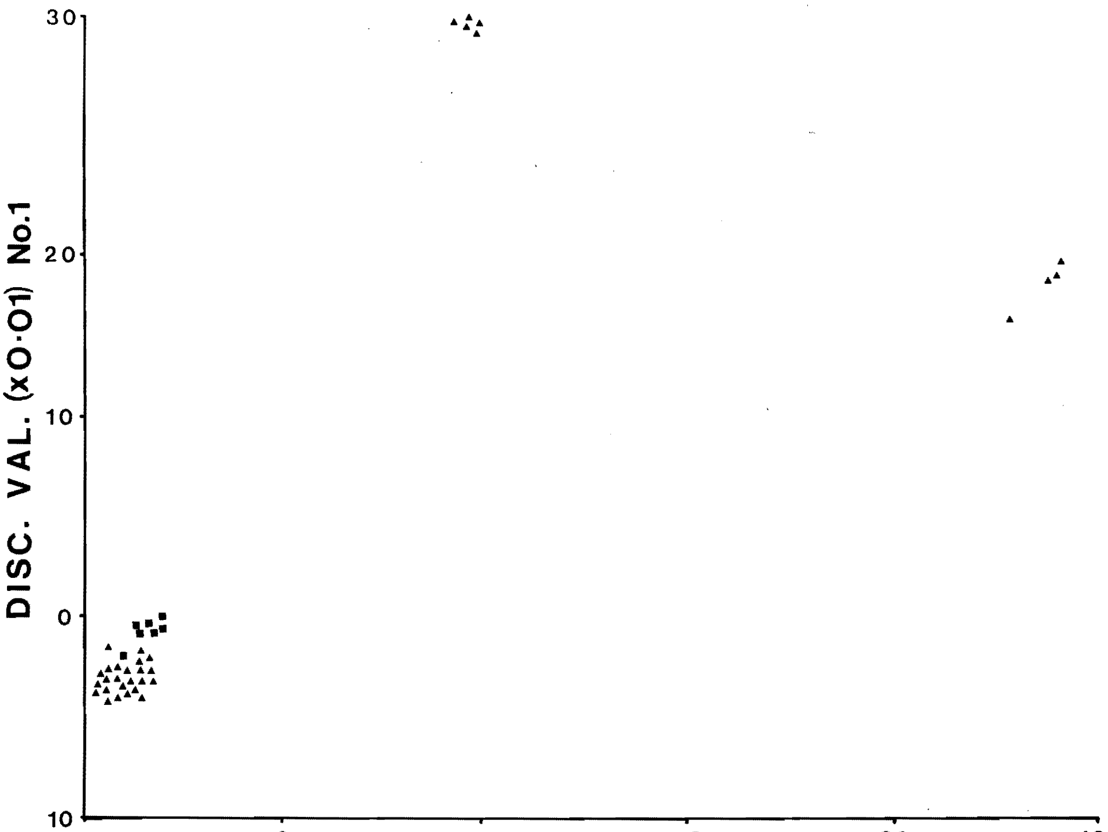
Fig 19, the combination of discriminant values 3 and 4, shows a slightly different picture. There is somewhat more distinction between groups 3 and 4, but less between 1 and 2 although they are still well separated from the other two. Function 4 is the better discriminant of groups 3 and 4 in this case but there is little to choose between either function when it comes to discriminating groups 1 and 2.

4.6 Conclusions

Discriminant analysis has therefore defined four

FIGURE 18

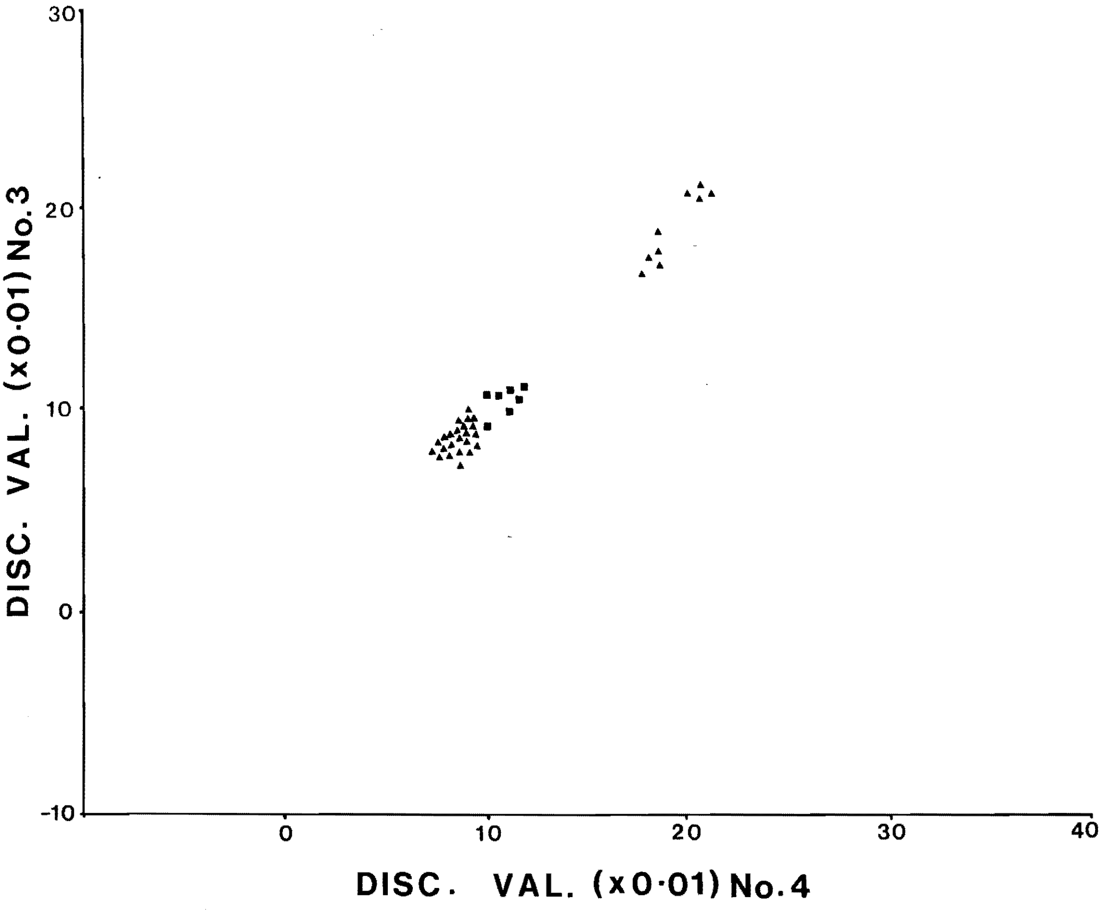
Graphical representation of the separation of faunistic groups derived from discriminant analysis. Functions 1 and 2.



DISC. VAL. (xO·O1) No.1
30
20
10
0
10
0
10
20
30
40
DISC. VAL. (xO·O1) No.2

FIGURE 19.

Graphical representation of the separation of faunistic groups derived from discriminant analysis Functions 3 and 4.


30
20
10
0
-10
DISC. VAL. (x0·01) No.3
0
10
20
30
40
DISC. VAL. (x0·01) No.4

groups but poorly differentiated the sandy and sandy mud regions. It has done an excellent job of defining the most obvious feature of the benthos, the *Chione* bed. It has also produced a somewhat spurious group that is not readily related to any observed grouping.

This method in this instance does not on the face of it seem to be as good or accurate as Fager's analysis. It is possible that with further refinement it may be made to work since it has been shown to have considerable potential on a smaller scale by Cassie and Michael (1968).

SECTION 5

DISCUSSION

5.1 The significance of the results

It would appear from the results of both the recurrent groups analysis and the multiple discriminant function analysis that assemblages of animals do occur in Lyttelton Harbour. It has been suggested in Section 4 that there is also a continuum composed of species that are not tied to one region but exist over a range of bottom types. Generally these have been found to show an affinity with one substrate, either muddy or sandy, where they are more successful.

This type of study is investigating community structures on a small scale in a region that would normally be classified as a muddy-bottomed harbour and the fauna present lumped into one community.

The communities have been identified in relation to the substrate texture and organic carbon content. Towards these ends the substrate had to be categorized into sands, sandy muds, and muds. There are rather indefinite, and certainly arbitrary, distinctions but are necessary to reduce some of the variables and facilitate handling of the data. This type of approach is very common among benthic ecologists and was used extensively by Sanders (1958) in studies in Buzzards Bay. He found a very marked correlation between the amount of fine material, the concentration of chemical nutrients and the density of fauna. Fager (1968) found a strong relationship between a stable fine sand substrate and a well established epifaunal community off La Jolla, California. Rhoads and Young (1970) have gone further than this in their investigations. They looked at the influences of deposit-feeding organisms on community stability and found that when the mud bottom was loosened by the reworking of the material the material clogged the filtering apparatus of suspension feeding animals, buried newly settled larvae or discouraged further settling of larvae, and prevented the attachment of epifauna.

The influence of fauna on the sediments varies with the distribution of animals and the trophic-group distribution. Animals that are heterotrophic either are suspension or deposit feeders. Rarely are both systems used. Often, as has been shown in Lyttelton Harbour, there is a spacial disparity in the distribution of filter feeding and deposit feeding forms. The general rule in this respect appears that suspension feeders occupy regions of abundant water supply where currents provide a continual source of food particles. On the other hand, deposit feeders normally exist in areas of deposition where currents do not carry away the colloidal material, that composes most of the organic fraction. In this type of distribution individual tolerances play a great part in determining penetration, especially of filter feeders, into very fine sediment areas.

5.2 Lyttelton Harbour communities reviewed

It is proposed to call the community that has been identified in the muddy regions the Hemiplax hirtipes - Virgularia gracillima community. This is in accordance with the rules for characterizing species pur forward in Thorson (1957) which require characterizing animals of the first order to occur in at least 50 percent of the samples taken and compose at least 5 percent of the living weight per standard unit. This situation must extent over the entire area of the community. These rules are based on the definitions proposed by Petersen (1924) and later modified by Sparck (1937). Hemiplax and Virgularia fulfil these conditions adequately in this case and both are very easy to recognise, there being no other species of the same genera in the harbour.

Characterizing species of the second order may be defined as those species that are found only in some parts of the community where they again must be found in at least 50 percent of all samples and make up at least 5 percent of the biomass. Taking up this role are Xymene plebejus and Micrelenchus huttoni. These two gasteropods, one a carnivorous whelk and the other a herbivore, have distributions that are somewhat governed by the availability of food but nevertheless are widespread over the community area. They correspond to the concept of "mosaics" proposed by Davis (1925).

The third part to this compound definition is the third order characterizing species that must be found in large quantities in up to 70 percent of the samples. It must also be included within the framework of the present community. However it is not restricted to the region under investigation but also participates in the species complement of the surrounding regions. Into this category Pontophilus australis falls. This very mobile shrimp may be caught in very large numbers in the muddy regions but also sporadically outside these areas. While Pontophilus must be included in the community as presented, it cannot be used in defining the region as a typical mud bottomed association.

The fourth class of inhabitant is termed associated animals, usually transitory, or those making up less than 2 percent of the biomass in the average sample. This position is filled by the ophiuroid, Ophiomyxa brevirima and the polychaete, Platynereis australis. These, while not regarded as part of the formally described mud community, are transitory visitors occurring very rarely in samples but occasionally in quite large numbers.

The second community is termed the Zeacolpus vittatus - Pectinaria antipoda community. Following the requirements put forward for the first community the first order characterizing species are Zeacolpus, a herbivorous gasteropod that occurs in very dense beds exceeding 300 per square metre in places, and Pectinaria a tubicolous, detrital feeding, polychaete. Both of these have a very wide distribution over the sandy regions of the harbour.

Second order species in this community include Trochus tiaratus, a herbivorous gasteropod that is somewhat more restricted in its distribution than Zeacolpus, tending to become spare away from sites where alga is abundant. The other is Myadora striata, a pelecypod forming small but locally dense beds within the sandy areas.

Third order species that occur in the sandy community but also range over the boundaries include the asteroid Asterina regularis and the cuttle fish Sepioloidea pacifica.

Associated animals are quite numerous with many straying in from the sandy mud continuum regions. The major species in this Category are Owenia fusiformis, Zegelerus tenuis , Nucula hartvigiana, which also forms very small beds in the community, and Spisula aequilateralis.

The third grouping as disclosed by the results of Fager's recurrent groups analysis may be better termed an association rather than a community. It is composed of opportunist species, Ostrea heffordi, Halicarcinus whitei, and Sigapatella novaezelandiae. As has been elaborated in Section 3, fauna, these have been designated shelterers and settlers. This will then be called the Ostrea - Sigapatella association. Establishment of this association requires the presence of empty shells or any solid based material, including rubbish dumped in the harbour. Because of this restriction the associations are very localized and spread throughout the harbour. Because this type of assemblage is relatively independent of the immediate substrate the established association may include representatives of either the Zeacolpus - Pectinaria community or the Hemiplax - Virgularia community.

The final community that has been isolated, particularly well by multiple discriminant analysis, is the Chione stutchburyi community. The first order characterising species is obviously Chione. There are very few other infaunal species associated with the Chione beds since with biomasses of 7000 to 9000 grams per square metre the seafloor is literally paved with the valves. Second order species that do occur include Pontophilus, Asterina, the epiphytic coelenterate Anthopleura aureoradiata and, towards the edges of the community, Myadora. There are no true third order animals but there are a number of small motile crustacea that come under the classification of associated animals. These include the amphipods, Corophium acherusicum and Paradexamine pacifica, and the ispod Isocladus armatus.

5.3 Comparisons with communities in other New Zealand harbours and inlets.

It is difficult to find evidence of similar communities from previous research into New Zealand benthic environments because the present study is concerned with the detail of communities over a very restricted region whereas most other studies (Oliver 1923, Fleming 1950, Dell 1951, Hurley 1959, 1964, Estcourt 1967, McKnight 1968b), have extended over relatively large areas of sea. In many cases these have been offshore studies of the continental shelf, or in southern fiords, neither of which has the same characteristics as the present study area.

Powell (1937) described the community structure of Auckland Harbour. The bulk of the harbour was found to have a sediment of a very fine nature with up to 93 percent sand and silt. This region, analogous to the muddy sand parts of Lyttelton Harbour, had as its characterizing species Echinocardium australe, a species that does not occur in Lyttelton. Species in the Echinocardium community that are common to both regions are Pectinaria australis, Owenia fusiformis, Atrina zelandica, Chione stutchburyi, Hemiplax hirtipes, Petrolisthes elongatus, and Chemnitzia zelandica. Most of the other species are northern forms that do not assume importance in waters south of the sub-tropical convergence.

In the sandy regions the dominants tended to be Maoricolpus roseus roseus and Trochus tiaratus along with Paphirus largillierti. In Lyttelton basically the same type of dominants are present with the place

Maoricolpus being filled by the very similar *Zeacolpus vittatus* and that of *Paphirus* by *Myadora striata*, pelecypod of similar habit to *Paphirus* (which itself is also rarely found).

The coarse shell sand bottoms in Auckland Harbour were found to be populated by a *Maoricolpus* community. In Lyttelton while great numbers of dead *Maoricolpus* shells were found in similar locations there were no living specimens present and these areas were occupied by a spare *Zeacolpus vittatus* - *Pectinaria antipoda* community. From consideration of the condition of the *Maoricolpus* shells of the Lyttelton stations the hypothesis that there has been a switch in dominance from *Maoricolpus* to *Zeacolpus* is further reinforced. Most of them are completely intact and still well coloured showing little sign of the erosion and decay that would be expected if they had been lying in the surface sediments for any length of time.

Where there are beds of pelecypods Powell's result showed a much more diverse faunal list with nowhere near the same dominance being exerted by the species concerned.

In Auckland this type of community was found in the channels of the outer harbour where the currents had maintained a moderately sandy texture and removed deposited silt. This situation corresponds well to that in Lyttelton where the incoming tidal flow has the same effect. The Auckland fauna while dominated by the two bivalves *Tawera spissa* and *Glycymeris laticostata* also have 18 species listed as subdominants. This contrasts with only 7 rather rarely found species in the Lyttelton situation. This may partly be explained by looking at the position of the Lyttelton bed of Chione. There is a very abrupt change from the sandy region to a mud substrate which has been shown to be relatively depauperate in species. Because of this there may be little scope for migration in from surrounding regions of competitive species. This together with the physical attributes of the region that seem to make it ideal for the establishment of the Chione combines to create a uniquely pure assemblage of animals. The density of Chione is not exceptionally high, similar concentrations having been found in a nearby estuarine habitat (Voller 1972).

Powell found a definite correlation between bottom type and the communities existing on them and proposed that a succession was occurring with the changing of the bottom from the original muddy state of the harbour floor to a hard stabilized substrate with the addition of shell fragments.

Estcourt (1967) in investigating the fauna of the sheltered parts of Marlborough Sounds was dealing with a stable, well established muddy bottom. This superficially bears some resemblance to the state of the upper portions of Lyttelton Harbour but the fauna, rich in northern warmer water species, was generally almost totally different. Chione stutchburyi was found at only one station, although large numbers of dead shells were dredged. Hemiplax hirtipes was present but Virgularia gracillima was not found at any sites sampled. The role of the ophiuroid Ophiomyxa brevirima was taken in the sands by the northern species Amphiura rosea and A. norae. Golfingia cantabriensis, a sipunculid taken in Lyttelton Harbour in very small numbers was present as was the large horse mussel

Atrina zelandica. There is some resemblance in the assemblages where the substrate is slightly more sandy at the mouth of Pelorus Sound, station C863, with the association of *Ryenella impacta*, *Petrolisthes novaezelandiae*, *Ostrea lutaria*, *Terebratella haurakiensis* amd *Chlamys gemmulata*. Both *Ryenella impacta* and *Chlamys gemmulata* are present as sub-dominants in the sandy mud regions of Lyttelton Harbour but the other 3 genera are represented by different species; *Petrolisthes elongatus*, *Ostrea heffordi* and *Terebratella inconspicua*. This assemblage was in a position where it was influenced by tidal currents in much the same fashion as the sandy mud regions of Lyttelton. Estcourt found that nearby, out of the current's influence, the dominance had changed and the ophiuroids were dominant again.

Ralph and Yaldwyn (1956) conducted a study in Otago Harbour near the Portobello Marine Biological Station and identified two associations that bear a great resemblance to those of Lyttelton Harbour.

The first of these termed the *Chione* (*Austrovenus*) association had the dominants *Chione stutchburyi*, *Macomona liliana*, and the polychaete *Arenicola assimilis*. The substrate was sandy mud with a black sulphide layer just below the surface. It was noted that there was a low concentration of macroscopic fauna.

In Lyttelton the situation is similar except that *Macomona* is replaced by *Myadora*, a very similar species and the polychaete is not present. Ralph and Yaldwyn also recovered two small curstacea *Callianassa filholi* and *Lysiosquilla spinosa* living in burrows among the shells. This niche was occupied in Lyttelton by two species of amphipod Corophium acherusicum and Paradexamine pacifica living down among the shells where they projected above the substrate surface. Another species common to both associations is the small anemone Anthopleura aureoradiata usually found epizooic with Chione.

Also recognised (in Otago Harbour) was a sub-community where the two polychaetes Aglaophamus macroura and Platynereis australis became numerous along with the small gasteropod Micrelenchus tenebrosus. This situation, probably best regarded as an ecotone between the Chione community and the adjacent sand and mud communities, also exists in Lyttelton Harbour where the gasteropod is Micrelenchus huttoni - an almost identical species.

The second recorded community in Otago Harbour is called the Maoricolpus association. The characterizing species in this community are Maoricolpus roseus roseus, Harmothoe praeclara and Ophiomyxa brevirima. In addition to these subdominants included the tiny gasteropod Chemnitzia zelandica, Zeacolpus vittatus, Halicarcinus cooki, Hemiplax hirtipes, and four species of the amphipod genus Parawaldeckia. This corresponds to the Lyttelton sandy community fairly well with Maoricolpus replaced by Zeacolpus and Harmothoe praeclara by Pectinaria antipoda. Ophiomyxa although present is not in the case of Lyttelton a dominant but is replaced by Asterina regularis which is common over all of the sandy and sandy mud communities. Chemnitzia in Lyttelton is confined to the sandy areas but its insignificant size makes it unsuitable as a characterizing species.

5.4 The continuum related to the communities

Mills (1969) refers to the idea that communities are not objective, clearly defined ecological units but might be abstractions from continua of distribution. To a degree this is dependent on the adoption or otherwise of the individualistic concept that was originally proposed in connection with identification of plant associations (Gleason, 1939). The individualistic hypothesis abolishes hierarchies that are the basis of community definitions. In many biological fields this has been regarded as a renegade concept by workers who have recognised discrete units. These they have combined to form groups. The basis of the conservatism has been the need for classification. Krajina (1961) asserted that the continuum cannot replace the classification. Every science has a classification of its subjects of research and without classification there can be no science of vegetation. Daubenmire (1966) admitted that there was a continuity of vegetation but supported the community system with the statement that there must be a framework for organizing, storing, and retrieving information. He advocated a system that allowed maximum predictions to be made about the unit.

This type of argument applies equally well to the identification of marine continua or communities and the same conflicts of interest have occurred. Lately, however there has been an increase in the number of workers postulating continua. These have tended to be more common among workers investigating plankton or micro fauna where boundaries of units are particularly hard to fix (Wieser, 1960; Kilburn, 1961).

The existence of a continuum in Lyttelton Harbour, or any other similar environment, depends on the presence of a gradient. In the present study this exists between the extreme of the muddy community and the sand community. The sandy mud intermediate is maintained by currents and appears entirely stable.

Two continuum species have an even spread over the entire region, also penetrating both nearby communities. These are Asterina regularis and Sepioloidea pacifica. In Fig.17 they are shown affiliated to both the Hemiplax - Virgularia and Zeacolpus - Pectinaria communities. All of the other species comprising the continuum are associated with either the muddy or sandy regions. Ophiomyxa brevirima, Platynereis australis and Nectocarcinus antarcticus are not abundant in the very muddy regions. There is no well defined point where the populations are maximal but they begin to disappear as the influence of the tidal current near Quail Island influences the texture of the substrate and produces the evenly sorted coarser grades.

Achelia variabilis, Owenia fusiformis, Zegelerus tenuis, Nucula hartvigiana, Maorimactra ordinaria and Austromitra rubiginosum are the remaining members of the continuum that inhabit the sandier regions and are associated with the Zeacolpus - Pectinaria community. The gasteropod Austromitra and polychaete Owenia both were restricted to the coarser regions of the continuum area while the pycnogonid Achelia and gasteropod Zegelerus showed a greater tolerance to muddier conditions. The pelecypods Nucula hartvigiana and Maorimactra ordinaria appeared to require rather more rigid conditions and consequently occupied restricted zones within the continuum, (see Figs. 15.21 and 15.22).

5.5 Human activities influencing the community/continuum complex

Lyttelton is a working port serving Christchurch and has been for the last 100 years. As such a large tonnage of shipping pass through the waters annually. Oil spillages from ships berthed at the bulk oil storage terminal near the wharves area entrance and from vessels passing up and down the harbour are becoming more common. The Harbour Board patrol vessels are equipped with detergent spraying equipment and such slicks are usually dispersed or sunk. Most of this material affects the middle harbour region from the wharf area to the mouth of Purau Bay. There is a conspicuous lack of variety of benthic fauna in the waters near the wharf area entrance and the sediment have an oily feel and appearance. Inside the mooring basin the bottom is very polluted and composed of an evil smelling ooze that is practically abiotic.

Further afield the pollution is mainly in the form of dumped rubbish thrown overboard from large vessels and pleasure craft. This does not seem to have any great effect and, as been mentioned earlier, may provide extra attachment surfaces for sessile species. Sewage enters the water in a semitreated form from many dwellings around the harbour shores and from pleasure craft that become very numerous during weekends. However relative to the size of the harbour this is a minor consideration at present and is not thought to have any deleterious effect on the quality of the waters.

5.6 Summary

(1) Lyttelton Harbour has been described with regard

to its formation, local geography and hydrology. The extend of dredging by the "Peraki" and its effect on the depths has been estimated by comparing the bathymetry in 1849 and 1951. Also discussed was the annual range of temperatures and the influence from the waters of Pegasus Bay.

(2) A brief review of sampling equipment and modification made to improve their efficiency has been included. The hypothesis that sampling equipment must be selected according to the type of substrate and fauna expected was advanced. The box dredge, orange peel grab, and epibenthic sledge have been described and their relative efficiencies and specialities portrayed in histogram form. From perusal of this it was decided to use both the box dredge and epibenthic sledge in taking quantitative samples. Sorting techniques using sieves and hand picking were discussed.

(3) The origin of the harbour sediments was discussed in relation to the composition of the Lyttelton volcanics, the loess coating the crater slopes and possible transport by long-shore drift of material from the Waimakariri River catchment. It was noted that the sinking of piles for wharves suggested a considerable sediment depth. Distribution of the various types of sediment was found from samples taken to form a well defined pattern in the middle harbour. This was depicted in Fig.8 where the classifications muddy, muddy sand, and sand were used. These divisions were used through the thesis.

Hydrodynamic processes were discussed and related to observed current directions and intensities. Forty sites were selected as indicative of the main regions and the distribution of sediment displayed as histograms for each site. Parameters used to characterise sediments were explained and their limits established.

(4) In section 3 dealing with the fauna, brief mention was made of the benthic environment, particularly in connection with turbidity in muddy areas, and a full species list drawn up. A broad outline of the faunal assemblages related to the local conditions was given and particular attention paid to the apparent effects of the growth of a filamentous red alga. A table drawn up showed numbers of animals per square metre during the periods of no algal growth, heavy algal growth, and at a control site near the zone of algal cover. An abundance of filter feeders in the sandy mud areas and a similar abundance of deposit feeders in the muddy regions was shown. Twenty four indicator species that had been selected as abundant and distributed differentially over all sediment types had their distributions mapped on a presence or absence basis. Their ecology in the harbour was also discussed individually.

(5) An analysis of the structure of the fauna with the intention of defining communities was undertaken using Fager's recurrent group analysis and multiple discriminant analysis. Fager's analysis produced three groups that were taken to represent communities, one group that was later termed an association and a large number of species that did not occur associated often enough to correspond to a community. These were grouped into a continuum on the basis of knowledge of the area gained during the field work.

The multiple discriminant analysis produced four groups correctly identifying the <u>Chione stutchburyi</u> bed and the sand community. Again a mass of sites representing the continuum was assembled. Another group that could not be positively related to any species or sediment condition, was produced. The separation of the groups was shown graphically by plotting discriminant functions.

(6) Section 5 was concerned with the identification of the communities that had been postulated from the results of the analyses. A sandy group was termed the *Zeacolpus vittatus* - *Pectinaria antipoda* community and a muddy assemblage named the *Virgularia gracillima* - *Hemiplax hirtipes* community. The dense *Chione stutchburyi* bed was also called a community but a group of opportunist sessile and sheltering species was thought to be better called an association.

The present study was compared with that of Powell (1936) in Auckland Harbour, Estcourt (1967) in the Marlborough Sounds, and Ralph and Yaldwyn (1956) in Otago Harbour near Portobello.

Criticisms and justifications of the continuum concept were briefly discussed and the reasons for its existence in Lyttelton Harbour examined. It was suggested that this situation has developed because of the large range of sediments and the stability of these relative to the current paths.

Human influence on the harbour with reference to oil pollution, rubbish dumping, and sewage disposal was mentioned and it was concluded that at present the effects from this are small.

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APPENDIX (1) : Sediment analysis

(1) For sandy sediments;

The sample is dried and a subsample of 40 gm obtained by quartering of cones. A reference subsample is also taken at this stage. The subsample is accurately weighed and placed in the coarsest of a nest of sieves mounted on a shaking machine. After 30 minutes shaking each sieve is emptied out onto a sheet of glazed paper. Each fraction is then weighed to 0.001 gm. An error that could have an effect here is aggregation of grains. To allow for this 100 grains from each sample are counted and the percentage of aggregates subtracted from the total weight of the fraction.

(2) For muddy sediments;

Sieving is capable of analysing down to <u>phi</u> 4 or 0.062mm but below this value the pipette method is used. This relies for its sorting on the differential in the rates of fall of particles suspended in a water column. A subsample of 15 to 20 gm, or about 1 tablespoon full, is taken. Again a reference subsample should be retained.

The sample is treated with 50 ml of 10% hydrogen peroxide. When the initial reaction has stopped a small amount more is added and left overnight. This removes all the organic material. A solution containing 0.6 gm per litre of calgon (sodium hexa-meta-phosphate) is made up and used to flush the muddy sample through a 0.062mm sieve designed for wet sieving. The calgon acts as an antiflocculant preventing the fine silt and clay particles aggregating in solution.

The sand fraction is dried and treated as above while the mud fraction, that smaller than <u>phi</u> 4, is placed in a 1000 ml cylinder and dispersant solution added to make up 1000 ml. The suspension is now vigorously stirred without breaking the surface to the extent of creating air bubbles. A check for possible flocculation must now be made. This entails allowing the suspension to stand for several hours with regular observation. If flocculation is evident either more concentrated calgon solution or a smaller sample should be used. After establishing that there is no flocculation the column is well agitated and after 20 seconds a 20 ml pipette sample is taken from 20 cm depth. The time is critical and care must be taken that the pipette does not create turbulence or touch the sides of the cylinder. Nine 50 ml beakers are air dried and weighed to 0.001 gm. The initial sample is placed into one of the beakers and the pipette flushed out with a further 20 ml of distilled water which is also added to the beaker. The sample is dried for 24 hours without boiling and allowed to stand at room temperature for about 2 hours. This, accurately weighed and multiplied by 50, is the total weight of the mud fraction of the sand/mud sample. Further pipetting at pre-determined times and constant depth give the relative amounts of progressively finer particles up to <u>phi</u> 10.

In the present study the sediment, being marine, contained dissolved salts. These were removed by mixing the sample with distilled water, leaving for 36 hours, and decanting the clear liquid off. If the sample contains a large proportion of very fine, possibly colloidal material filtering is better than allowing it to settle.

APPENDIX (2) : Organic Analysis

Two methods are commonly used; loss of weight by combustion, and wet oxidation by hot chromic acid. Both of these have their advantages but wet oxidation avoids two of the principal drawbacks of loss of weight by combustion. These are the driving off of water contained in substrate colloids which is particularly important when dealing with fine textured muds, and the chemical conversion by heating of the calcium carbonate in the broken up shells that are almost invariably present.

The Walkley and Black method was originally developed for soil analysis, but providing a correction is applied for the concentration of sodium chloride in marine sediment samples, it is equally applicable in this field. Piper (1947) considers that the method recovers 75 to 80% of organic material while being unaffected by elementary carbon and nitrates.

The aim is to determine the concentration of available organic compounds in the sample assuming that the carbon present is proportional to the organic material. A correction factor of 1.8 calculated by Trask (1939) assumes that carbon comprises 56% of the organic molecules. Because only 75 to 80% of this material is recovered another correction of 1.3 may be applied leaving a nett figure of 2.4 by which all of the raw Walkley and Black determinations are multiplied. But not all of the carbon is in an assimilable form and there is some slight reaction with shell particles; accordingly 0.4 is subtracted from the determination of all shelly grades.

The modified Walkley and Black method, as detailed by Morgans (1956), is carried out as follows. Subsamples of about 2 grams are oven dried at 105°C for 24 hours. The samples are accurately weighed and placed in individual dry flasks. It is recommended that eight to ten be done simultaneously since individual treatment is a time consuming process. Ten mls of N potassium dichromate and 20 mls of concentrated sulphuric acid are added, the acid being dispensed slowly while violent effervescence occurs. The material is now left to react for 30 minutes.

Two hundred mls of water, 10 mls of 85% phosphoric acid and one ml of diphenylamine indicator are added. The indicator is made up by dissolving 0.5 grams of diphenylamine in 100 mls of concentrated sulphuric acid and 20 mls of water.

The solution is titrated with N ferrous sulphate, which has previously been standardized against the N potassium dichromate, until the solution is blue. Further sulphate is added until a sudden green change appears. Another 0.5 ml of dichromate is added and ferrous sulphate added dropwise until the blueness just disappears. Although the blue colouration normally reappears as the further 0.5 ml of potassium dichromate is added this may not happen until titration is begun

Calculation is based on the principle that 1 ml of potassium dichromate is equivalent to 3 mg of carbon. The equation given below expresses the carbon present as a percentage of the original sample.

$$\text{percent C} - \frac{V1 - V2}{W} \times 0.003 \times 100$$

where V1 - the volume of potassium dichromate

V2 = the volume of 1N ferrous sulphate

W = sample weight

Errors Present

In many sediment samples it is not practicable to attempt to remove the salt before analysis. This then will react with the chromic acid forming free chlorine. The loss of chromic acid is corrected for by subtracting one twelfth of the percentage of chlorine in the sample from the calculated organic carbon value.

The second error, and a potentially more serious one in Lyttelton Harbour, is that of particles of coal reacting with the oxidizing agent. This is particularly apparent in samples from the mid harbour region, near navigation channels and came to light after investigation of some suspiciously high determinations. After this any unusually high results were checked visually for the presence of particulate coal.

APPENDIX 3: Summary of raw sediment data

SITE	DISPERSION	SKEWNESS	KURTOSIS
c37	0.41	1.6	8.2
c23	0.77	1.2	6.1
d24	0.62	-1.0	7.2
d27	0.18	2.0	7.7
e20	0.44	-1.4	7.2
e21	0.79	1.9	6.9
f23	0.83	-2.2	2.9
g9	0.22	0.5	4.0
g12	0.54	0.7	8.2
g14	0.72	3.4	7.6
g20	0.99	1.4	7.4
g22	0.64	-0.1	7.9
g22	0.72	0.2	7.7
g23	0.33	-0.4	6.8
g24	0.42	2.4	8.1
g28	0.58	-0.2	7.8
h6	0.71	1.1	4.8
h8	0.63	3.4	3.6
h10	0.52	0.2	6.6
h11	0.31	0.7	3.8
h12	0.44	1.4	6.0
h18	0.43	1.1	5.2
h19	0.61	1.6	7.7
h20	0.29	3.1	5.8
h20	0.60	0.1	4.4
h21	0.29	-1.4	6.1
h22	0.84	1.2	7.7
h23	0.57	-0.4	5.9
i4	0.54	0.4	4.6
i7	0.42	0.6	6.1

SITE	DISPERSION	SKEWNESS	KURTOSIS
i12	0.71	0.1	7.7
i13	0.69	0.2	7.9
i15	0.54	2.7	7.8
i16	0.56	-1.1	8.1
i19	0.61	2.4	8.8
i20	0.51	1.8	6.9
i21	0.59	2.4	5.8
i22	0.58	-1.8	1.9
i22	0.53	-2.2	8.7
i23	0.51	-2.1	6.3
i23	0.42	-0.1	6.8
i24	0.55	0.2	1.9
i25	0.39	-0.3	2.3
j5	0.62	1.2	3.9
j9	0.70	2.1	4.1
j10	0.63	0.1	6.0
j11	0.59	1.7	7.9
j13	0.54	2.4	7.2
j13	0.61	-2.2	7.2
j14	0.51	-0.1	6.1
j15	0.42	3.8	8.1
j19	0.51	0.4	8.4
j21	0.49	-1.1	3.8
j24	0.62	0.3	6.1
k4	0.71	3.8	7.2
k4	0.72	4.1	6.4
k8	0.60	2.2	3.1
k13	0.58	0.3	4.9
k14	0.31	0.1	3.5
k22	0.36	1.1	7.7
k23	0.42	-0.3	6.9

SITE	DISPERSION	SKEWNESS	KURTOSIS
l3	0.59	2.2	4.1
l12	0.60	0.6	7.2
l16	0.71	-1.2	4.8
l22	0.43	2.1	6.9
m4	0.51	2.2	7.2
m15	0.54	1.7	6.8
m22	0.57	0.7	4.7
n12	0.49	0.3	6.0
o14	0.48	-1.1	6.8
p11	0.37	-0.4	5.8